# OPERATIONAL AND COST MODELS FOR HIGH-SPEED RAIL AND MAGLEV SYSTEMS

By

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A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

1993

To my parents,

Emil and Maggie

# ACKNOWLEDGMENTS

I would like to extend my deep gratitude to Dr. Fazil Najafi, my supervisory committee chairman, for his guidance and encouragement. Without his continuous support this study would not have been possible. Sincere appreciation goes to Dr. Paul Thompson, Dr. Ralph Ellis, Dr. Joseph Wattleworth, and Dr. Sharma Chakravarthy for their suggestions and comments and for serving on my supervisory committee.

Additionally, I like to thank Mr. Fritz Polifka, managing director of Transrapid testing facilities in Germany; Mr. Rolf Hellinger of the German National Railways (DB); Mr. Gabriel Courbey of the French National Railways (SNCF); Mr. Joseph Silien, a representative of ABB of Sweden; Mr. John Harrison of Parsons Brinckerhoff Quade & Douglas; Mr. Nazih Haddad and Mr. Jack Heiss of the Florida Department of Transportation; Mr. Ron Mauri, Mr. Pete Montague and Mr. Jim Milner of the United States Department of Transportation; and Mr. Robert Casey of the High Speed Rail/Maglev Association. The technical assistance provided by these individuals was very valuable.

Finally, much gratitude is owed to my parents, Emil and Maggie, for their love and support during the entire course of my study; and to Dörte Saße for adding colors to my life.

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# GLOSSARY

| | |
|---|---|
| Ballast: | Crushed rock that supports the rails and distribute the train's weight. |
| Block Section: | Track is divided into sections for signaling purposes. |
| Catenary: | Overhead contact wire and the supporting structure to supply electric current to trains. |
| Consist: | Another word for a train. |
| Cut-and-cover: | A tunneling technique in which the track in built in a deep cutting, roofed with a reinforced concrete structure, and then covered with minimum amount of soil to restore the landscape. |
| Dynamic Brake: | Braking in which the traction motors are used as generators and convert kinetic energy into electric energy. It does not involve friction. |
| Eddy-Current Brake: | Braking system based on magnetic attraction. It does not involve friction. |
| EDS: | Electrodynamic levitation system for maglev. |
| EMS: | Electromagnetic levitation system for maglev. |
| FAA: | Federal Aviation Administration. |
| FDOT: | Florida Department of Transportation. |
| FRA: | Federal Railroad Administration. |
| HSGT: | High-speed ground transportation system. |
| ICE: | Intercity Express, a German high-speed rail system. |
| Maglev: | Magnetically levitated train. |

| | |
|---|---|
| Pantograph: | The current collecting device located on the roof of a train. |
| SNCF: | French National Railways. |
| USDOT: | United States Department of Transportation. |
| Rolling Stock: | The fleet of trains. |
| TGV: | A French high-speed rail system. |
| Tie: | The transverse part of the track infrastructure to which the rails are attached. Also called sleeper. |
| Trainset: | A train consisting of a fixed formation of several passenger sections (usually articulated) and a power car at one or both ends. It is handled as one unit. |
| Transrapid: | A German EMS maglev system. |
| Truck: | The structure housing the axles and suspensions and upon which rests the car body. Sometimes referred to as bogie. |
| ABB X-2000: | A Swedish high-speed rail system with a cab body tilt mechanism. |

Abstract of Dissertation Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Doctor of Philosophy

# OPERATIONAL AND COST MODELS FOR HIGH-SPEED RAIL AND MAGLEV SYSTEMS

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August 1993

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High speed ground transportation (HSGT) has been recognized by European and Southeast Asian countries as a necessary component of a balanced transportation policy. The governments of these countries took the lead in promoting and funding HSGT systems. In the United States, it was hoped that the private sector will undertake the development and financing of HSGT systems. Such hopes, however, did not materialize because none of the proposed projects was implemented. Currently, there is a renewed public and private effort to reexamine the merits of high-speed rail (HSR) and magnetically levitated (maglev) systems.

Both HSR and maglev systems offer comfortable and safe ground transportation at high speed. These systems, however, differ significantly in technology, cost structure, and operational and cost sensitivity to design changes.

The dissertation objectives are to describe the characteristics of the various systems operational today, develop an operational simulation model, study the cost structure of HSR and maglev projects, and formulate a simplified cost procedure for quick and efficient preliminary feasibility analysis of potential corridors.

The operational model simulates the operation of HSGT systems, taking into consideration systems' performance characteristics, comfort criteria, and route alignment. Default performance parameters for 14 systems were obtained and included in the model. New systems can be added easily.

The simplified cost procedure relies on a database software. The procedure's overall structure is described and illustrated with a model written in dBase IV. The model is interactive. Menus are provided for efficient data input. Cost estimation is performed in two steps: first, menus are used to generate a file containing the codes of the project's main items for each segment of the route; second, the model interacts with a separate unit cost database and replaces item codes with corresponding unit costs. Finally, menus allow the user to generate various types of cost summaries. The cost model supports programs that can be used to automatically capture input errors, upgrade unit costs, and perform cost adjustments to reflect job condition, soil type, location and other factors.

# CHAPTER 1
# INTRODUCTION

## General Background

High-speed ground transportation (HSGT) systems have been recognized by European and Southeast Asian countries as an important component of a balanced transportation policy. The governments of these countries took the lead in investing directly or indirectly in the development and/or implementation of HSGT systems. Japan and France were the first countries to start the HSGT race, motivated primarily by energy conservation goals and to reduce their dependency on imported oil. The technical and commercial success of the early Japanese and French high-speed lines led to a growing worldwide interest in this new form of ground transportation.

High-speed rail (HSR) and magnetically levitated trains (maglev) are the two modal components of HSGT. The HSR is an advanced conventional steel wheel and steel rail system engineered for speeds of 240 to 350 km/h (150 to 220 mph). Three decades of revenue service have established HSR as the safest and most energy-efficient transportation mode. Nevertheless, maglev technology is being advanced as an even safer and more efficient transportation mode. Maglev trains generate lower noise and vibration levels than HSR systems.

They are also capable of climbing steeper grades and consequently cause little disruption to the environment. Maglev systems are the fastest and most technologically advanced ground transportation mode. They rely on magnetic forces to support the train above the guideway, providing for contactless operation that permits speeds of up to 500 km/h (310 mph). Electromagnetic forces provide levitation, guidance, propulsion and braking (Johnson et al., 1989).

Nations all around the world are expressing interest in HSGT systems. The European Community has proposed an ambitious master plan to link most major West European cities with an HSGT service. It is estimated that by the year 2015, the European HSGT network will consist of over 28,800 km (18,000 mi) of routes including 18,880 km (11,800 mi) of new lines or lines upgraded for speeds of more than 250 km/h (156 mph) (Vranich, 1991). The proposed European HSR network is illustrated in Figure 1-1. Japan is continuously upgrading its rail links and planning new HSR lines. It is also developing two maglev systems using conventional and superconducting magnetic technologies. South Korea is designing an HSR system between Seoul and Pusan. The line is scheduled for completion in 1998 at a cost exceeding $8.3 billion. Taiwan is planning a 320 km (200 mi) HSR system between Taipei and Kaohsiung at a cost estimated between $12 billion and $15 billion (Vranich, 1991). The planned HSR lines in South Korea and Taiwan are shown in Figure 1-2. Australia is considering an HSGT link

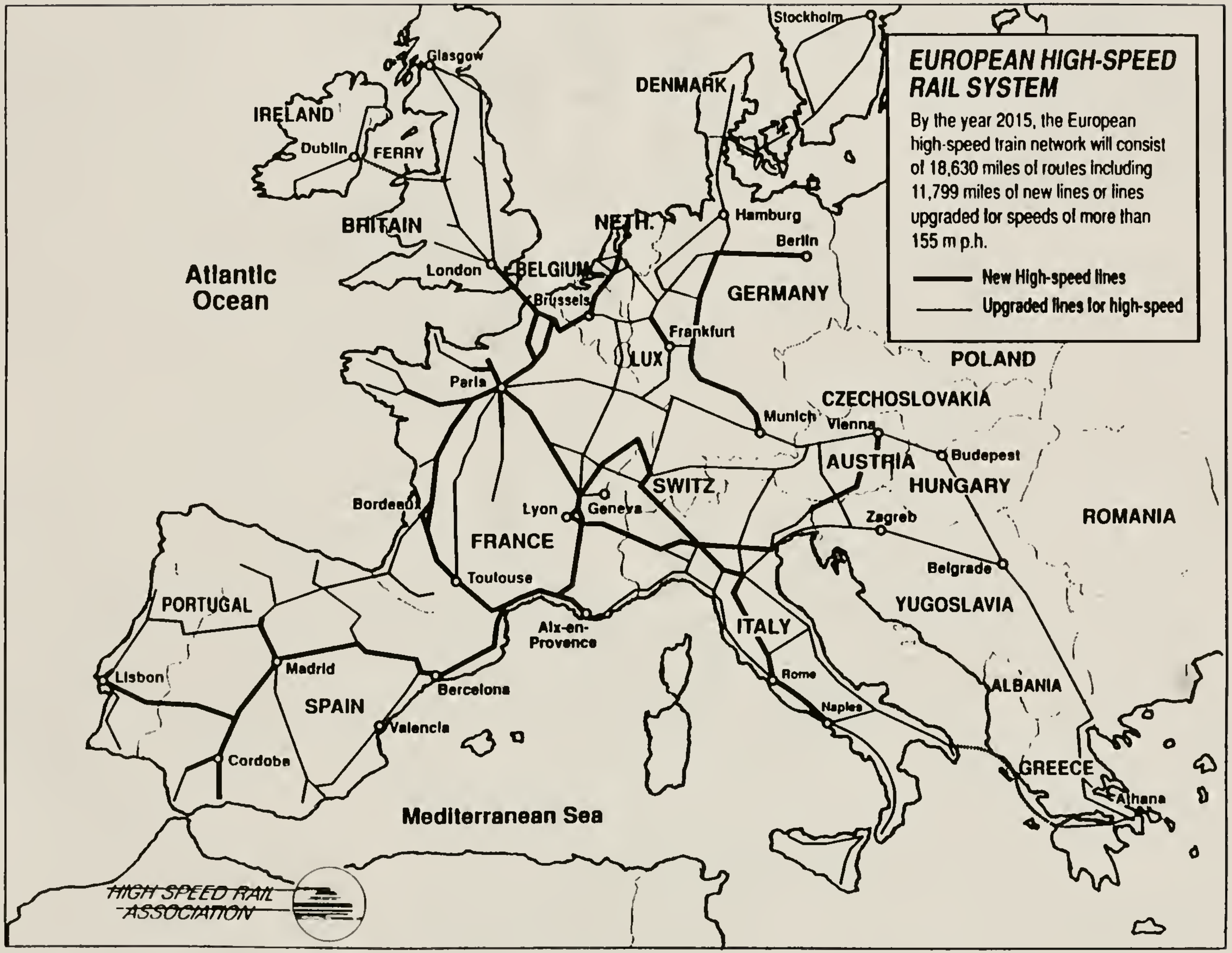


Figure 1.1: Proposed European HSR Network for the Year 2015

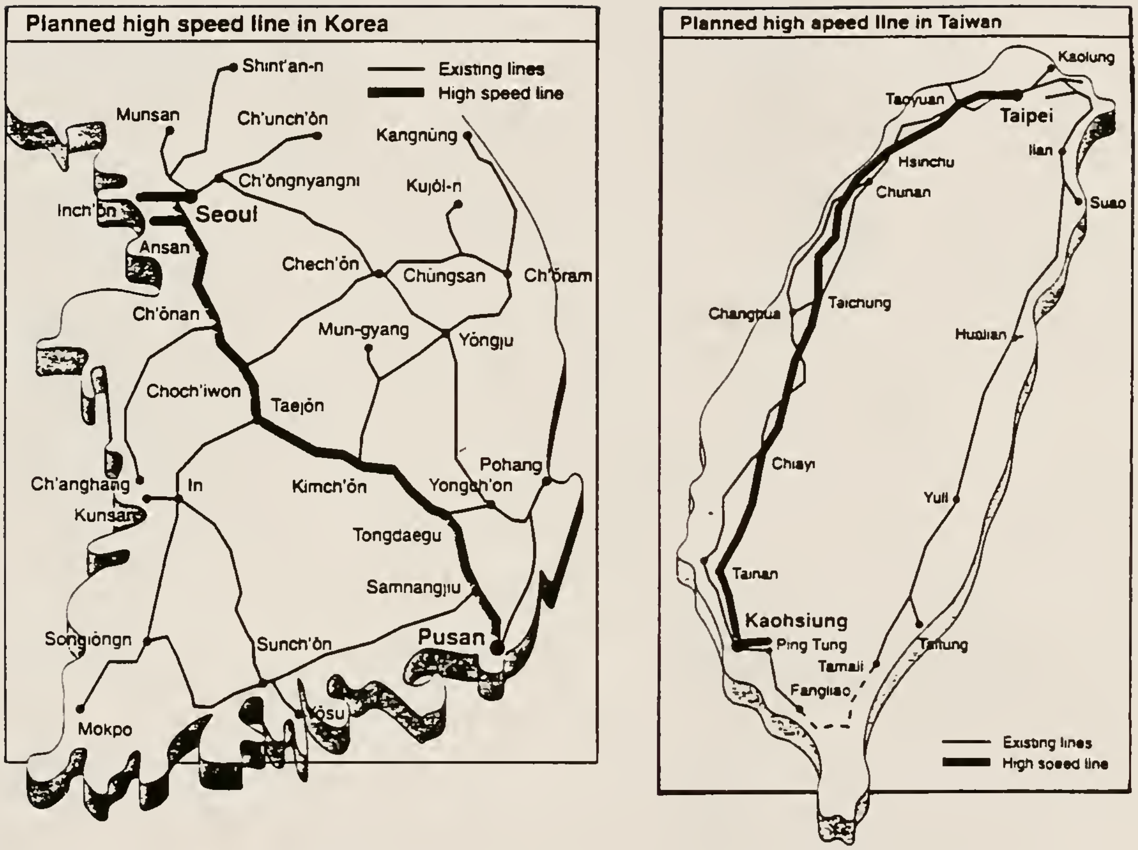


Figure 1-2: The HSR Planned Lines in South Korea and Taiwan
Source: ICE, 1992.

between Sydney and Melbourne. China has announced a joint venture with Japanese firms to plan a 280 km (175 mi) high-speed train connecting Fuzhou with Xiamen by 1997 (Speedlines, April 1993). France and Great Britain will soon be linked by the Eurotunnel, an all-weather HSR system operating in a tunnel dug under the English Channel. The Eurotunnel is the largest, privately funded civil engineering project in the world. The consortium in charge of the project includes over ten major international construction companies. The project management is assumed by Bechtel International (Bernard, 1992).

In the United States, interest in HSR and maglev systems is growing as a response to air and highway congestion. The Department of Transportation (USDOT) predicts a continuous increase in travel demand, further straining the already congested highway facilities; and the Federal Aviation Administration (FAA) estimates an even larger increase in air travel. According to the American Association of State Highway and Transportation Officials (AASHTO), surface travel demand is expected to at least double by the year 2020 (Vranich, 1991). The House of Representative's bill H.R. 1087 (U.S. House of Representatives, 1991) states that according to USDOT, over two billion hours are lost annually because of highway congestion, costing the economy $80 billion. A study conducted at the Argonne National Laboratory (Johnson et al., 1989) for the U.S. Department of Commerce states that in 1986, the cost of all air traffic delays amounted to nearly $5 billion. The H.R. 1087 bill estimates an annual loss of $8 billion due to airport congestion by 1987. The Argonne study also states that 22 airports are expected to exceed three million hours of annual passenger delay by 1996. Figure 1-3 shows the projected total aircraft delay at major airports.

The ability to expand highway capacity on congested corridors has frequently been hampered by high costs and limited rights-of-way. Proposals to build new airports or expand existing ones have faced strong community opposition (TRB, 1991). In corridors where highway and airport expansions are prohibitively expensive or infeasible, an HSGT link could provide needed capacity to insure adequate mobility to the traveling public. One HSR line can carry as many passengers as six lanes of highway, depending on operation frequency. Furthermore, HSR and maglev systems are potentially attractive competitors to air travel for distances between 150 km and 950 km (about 100 mi and 600 mi). They offer travelers the advantages of frequent departures, comfort, economy, safety and reliability in all weather conditions. While airports are built outside urban areas, train stations are usually located near the center of the city, thus significantly reducing the overall travel time (i.e., perceived trip time) of short trips. The Argonne study (Johnson et al., 1989) estimates that between 38% and 50% of airline trips consist of distances of less than 960 km (600 mi) such as those shown in Figure 1-4.

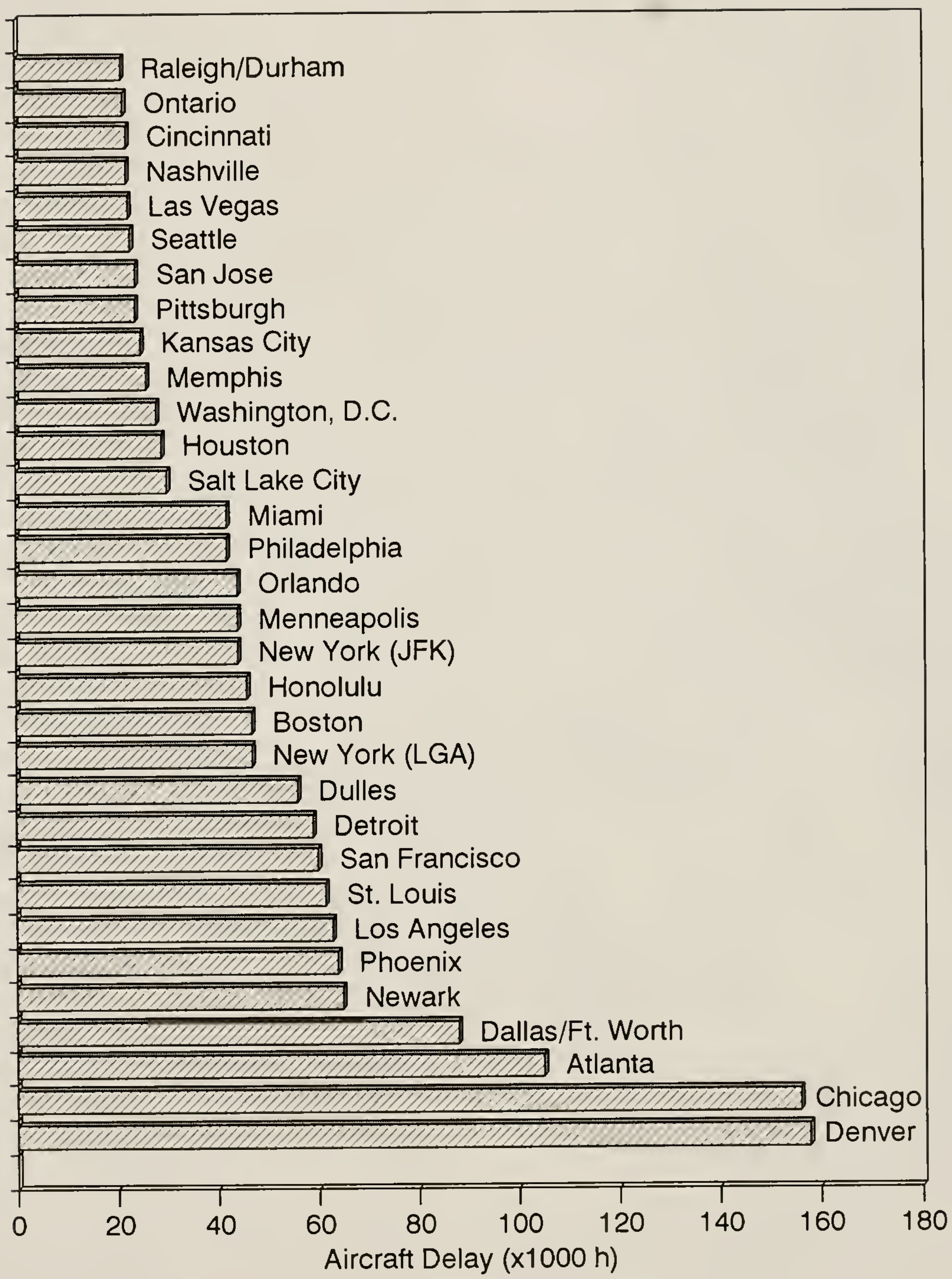


Figure 1-3: Projected Total Aircraft Delay For Major Airports by 1996
Source: Price, 1987

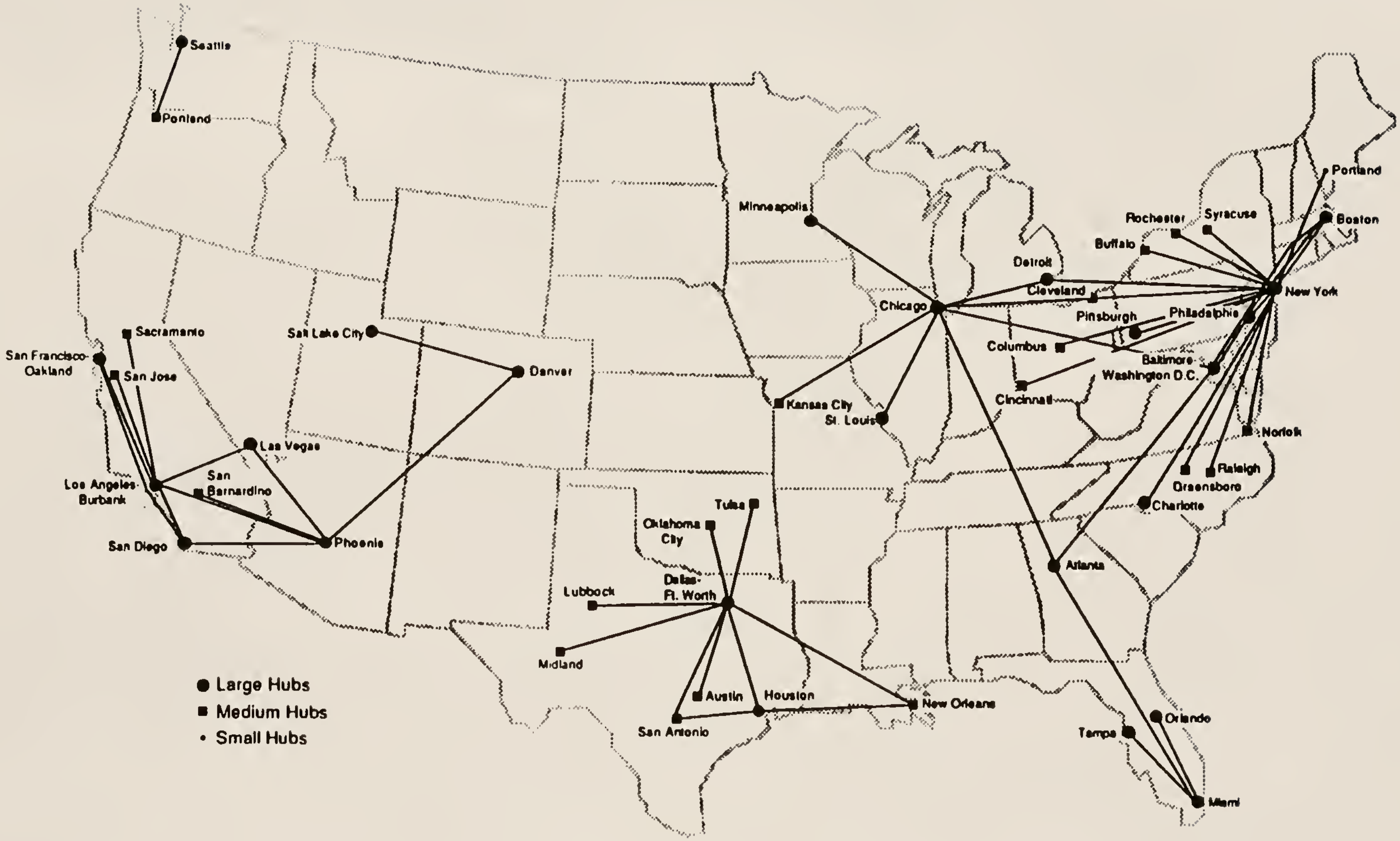


Figure 1-4: Top 50 Air Traffic Routes under 600 Miles
Source: Johnson et al., 1989.

## Problem Statement

Although both HSR and maglev systems offer comfortable and safe ground transportation at high speed, they differ significantly in performance, cost structure, maintenance requirements, noise emission and cost sensitivity to design changes. Maglev systems are typically elevated. HSR systems operate mostly at grade. As a result, the incremental costs for bridges, overpasses, and other special structures vary considerably between these two modes.

Maglev systems are more expensive than HSR systems, but they are capable of higher speeds and faster acceleration rates. Traveling at high-speed requires not only fast trains, but more importantly a track alignment with gentle horizontal and vertical curves to provide a comfortable ride. Curves cause lateral and vertical accelerations that reduce passenger comfort. Furthermore, operation at high-speed requires compatibility among track, equipment, sensors, communication and signaling systems (TRB, 1991). Unless track quality, route alignment, and signaling systems permit extended travel at maximum speed, the improvement in travel time will be marginal regardless of the technology used.

Travel time is the most important operational parameter in a corridor study. It is also a key factor in predicting ridership. Typically, travel time has been estimated by state officials in two extreme ways: the first is by conducting a detailed feasibility analysis, usually by hiring consultants;

the second is by performing some simplistic calculations based on the travel distance and the train's top speed. Detailed corridor studies are time consuming and costly. Furthermore, these completed studies have little value when the considered HSGT technologies are upgraded, or when changes in route alignment or station locations are desired. On the other hand, simplistic calculations based on the system's top speed and the estimated travel distance can be misleading. The reason is that the proposed HSGT alignments usually follow interstate rights-of-way or existing railroad tracks in order to minimize environmental and social impacts. However, the horizontal and vertical curves of the interstate system and existing railroad tracks are designed for relatively low speeds. This can severely limit the train's allowable speed and significantly increase travel time beyond what is acceptable to justify the high capital cost of an HSGT system. Therefore, alignment improvements are necessary on existing tracks or highway rights-of-way to accommodate HSGT systems. These improvements, however, must be carefully selected based on cost and operational impact analysis.

Preliminary cost estimates of HSR or maglev corridors have necessitated detailed and costly studies. This is because the topography and conditions of each corridor are unique. Past studies have shown a wide cost disparity between proposed systems, especially for maglev projects (as described in Chapter 7). There is a need to develop a simplified cost estimation technique that is not as detailed or costly as a full corridor studies, but that provides much better cost estimates than a comparison with the cost per mile of other projects. The cost estimation method should be based on an understanding of all the main cost components of an HSR or maglev system and should be designed to interact with a separate cost database of main items. The cost database should be easily maintained and upgraded. Several steps are required to develop this simplified cost model and the unit cost database of main items. In Chapter 8, the overall structure of the model is outlined and a sample program is developed to illustrate the model.

In summary, the selection of the appropriate HSGT system and the optimal route alignment requires the evaluation of a large number of alternate route/system configurations. This type of analysis is most efficiently performed with the help of computer-based techniques.

## Study Objectives

The objectives of this study are to examine the characteristics of existing HSR and maglev systems and to develop a simplified microcomputer-based analysis technique to perform fast and low-cost preliminary HSGT corridor evaluations. As previously mentioned, a preliminary study of an HSR or maglev corridor requires numerous simulation runs to select the appropriate HSGT technology and the most effective route alignment that balances cost and performance. Today's powerful microcomputers provide the ability to run sufficiently accurate simulations of train operation for varying route conditions. Furthermore, the advancement in microcomputer database software makes it possible to develop a menu-controlled cost model that allows rapid preliminary cost estimates of entire projects as well as selective design changes. The ability to consider numerous design alternatives requires that both the cost and simulation models be simple to use, menu controlled, and designed to easily incorporate new systems and updated cost data.

The development of a simplified computer-based analysis technique requires the following steps:

- Studying train movement dynamics and analyzing the characteristics of the various HSR and maglev systems operational today.
- Developing an operational simulation model that can quickly and accurately simulate an HSR or maglev train movement along any route. The simulation should take into consideration the performance characteristics of the system, track alignment, station locations and constraints such as allowable lateral acceleration and track superelevation.
- Developing the overall structure of a computerized cost model that interacts with a separate cost database to produce quick preliminary cost estimates of HSR and maglev systems.

The objective of the study is not to develop a detailed unit cost item database of main HSGT construction items. This is currently not possible in the United States because no HSR or maglev system has been built in North America, and foreign experience cannot be easily nor accurately translated. The objective is instead to develop the overall structure of a cost estimation procedure and illustrate its operation with a sample program. In addition, a preliminary cost database was developed by adapting cost estimates from previous HSR and maglev corridor studies conducted in North America.

The cost estimation procedure has the advantage of relying on a database software. Preliminary HSGT cost estimates have typically used spreadsheet programs (Schmelz, 1989). Spreadsheet programs are easy to use. They have, however, inherent limitations that can restrict a quick evaluation and representation of the costs involved in a project. A spreadsheet program presents a "two-dimensional" layout of a project's cost items. A database program is capable of developing a "three-dimensional" view of the project's cost items by storing cost information of each route segment in a different record of the file. A database software offers additional advantages such as the ability to develop menus for quick interaction and easy input of data, the capability to incorporate programs written in a host language to perform specific tasks, and the powerful query capability possible by creating relational databases.

The main feature of the cost model is its ability to automatically integrate new and updated cost databases as long as the coding system is respected. While item costs vary and a cost database needs to be updated regularly, HSR and maglev projects generally have a consistent cost structure. The cost model is based on this cost structure and is developed by studying the main components of typical HSR and maglev projects. Future improved unit cost databases of main items will enable the model to produce more accurate estimates without modifying its internal structure.

## Research Methodology

The study was completed according to the following main tasks:

### Task 1: Review of HSGT systems (Chapter 2)

The literature was reviewed to study the characteristics of the various HSR and maglev systems. The review emphasis was on operational systems or systems certified as operationally ready. Few academic books on the subject are available. The information was mainly obtained directly from the French, German and Swedish HSGT manufacturers; and from reviewing newsletters, scientific papers, periodicals and USDOT reports. The most advanced HSR and maglev systems were identified, and a description of each system is presented.

### Task 2: Comparison of HSGT Technologies (Chapter 3)

The information gathered in Task 1 was useful to perform a systematic comparison of the various HSGT technologies. This includes a review of the differences between HSR and conventional rail, a comparison of HSR and maglev systems, an assessment of the attractive and repulsive maglev technologies, and an examination of the advantages and disadvantages of tilt trains. The reasons for the wide cost disparity between the comparable French TGV (Train a Grande Vitesse) lines and the German ICE (Intercity Express) lines are also described.

### Task 3: Review of HSGT Literature (Chapter 4)

The literature review pertaining to HSGT technology dealt primarily with government reports and studies published by the Transportation Research Board (TRB). The proposals to build and operate HSGT systems in the U.S. were more focused on ridership estimates and financial feasibility than on technical analysis. Therefore, they were not reviewed in this task. Nevertheless, these proposals were used in task 6 to analyze the cost structure of HSGT projects and develop a preliminary cost database.

Some of the studies reviewed are the Argonne National Laboratory's report sponsored by the U.S. Department of Commerce; the Carnegie Mellon's study and the TRB Special Report, both sponsored by USDOT; the various safety reports produced by USDOT and the Federal Railroad Administration (FRA); studies performed by the Transportation Research Board (TRB); transcripts of congressional hearings; and the book titled Supertrains: Solutions to America's Gridlock written by

Joseph Vranich, the current president of the High Speed Rail/Maglev Association.

Task 4: Study of Train Dynamics (Chapter 5)

The simulation of an HSGT train operation along a route is deterministic because it is based on the laws of dynamics. The performance of an HSR or maglev train is governed by mechanical limitations and comfort limits. The train operation depends on the system's acceleration and deceleration rates, maximum speed, acceleration on grades, and allowable speed on vertical and horizontal curves. A train acceleration is a function of its tractive force minus the sum of all resistive forces. The tractive force is based on the engine's rated power. Resistive forces are estimated by various mechanical and aerodynamic formulas developed empirically or through field tests. Acceleration decreases with speed due to air resistance, which becomes the dominant resistive force at higher velocities. Grades reduce acceleration because they add a new resistive force equal to the component of the weight vector parallel to the ground.

A train traveling around a curve is subject to a centrifugal force acting outward. This force can be partially balanced by track superelevation. Higher speeds or sharper curves cause an excess lateral force that causes lateral acceleration and is sometime referred to as unbalanced superelevation. Similarly, vertical curves cause upward and downward accelerations. The allowable lateral and vertical accelerations are governed by passenger comfort criteria and mechanical constraints.

In addition to curves and grades, the simulation process takes into consideration station locations and externally imposed speed restrictions. A train must respond to changes in route condition several miles before it reaches them. This is achieved by developing at each route section a deceleration curve based on comfortable deceleration rates. Deceleration curves are compared with a route's allowable speeds to determine the proper time for the train to begin decelerating so it will not exceed the route's speed limits.

### Task 5: Development of the Operational Model (Chapter 6)

The purpose of the operational simulation model is to simulate the movement of an HSR or maglev system along a route and compute travel time and operating speed for each section of the route. The model's inputs consist of route data, system performance data, and comfort criteria such as banking angles and allowable lateral accelerations. The model's outputs include a speed profile and a summary table stored in an ASCII file that can be imported by most spreadsheet programs to produce graphical representations of results.

The program is written in FORTRAN because the simulation process requires extensive computations with floating numbers and FORTRAN is suitable for this kind of application. The FORTRAN language, however, does not allow easy interface with the user and is incapable of generating input menus.

Therefore, menus were created using the BASIC language to provide a graphical and easy way to input data and capture input errors. Because the FORTRAN simulation program uses all the available random access memory (RAM) available to a personal computer, the interface between the BASIC and FORTRAN programs is insured through a batch file that causes these programs to run sequentially.

A good deal of effort was spent on collecting performance data from the various HSGT manufacturers, located mainly in Europe. This effort was quite successful. Technical data describing the newest TGV and Transrapid trains (fully tested but not in revenue service yet) were obtained, as well as technical data related to the ABB X-2000 tilt train that started trial operation between Boston and New York in March 1993 and was tested in Florida in June 1993.

The technical data describing the performance characteristics of the various technologies were obtained in several formats. Some HSGT manufacturers provided speed-time or speed-distance profiles, others provided charts or equations of the tractive and resistive forces, and some provided graphs of acceleration vs. speed. Several spreadsheet programs were developed to translate these various types of data into the uniform input format acceptable by the model.

The operational simulation model was tested on hypothetical corridors and the simulated acceleration and deceleration operations were compared to manufacturers’ speed profiles. A small spreadsheet program was also developed to verify the model's simulation results. After the model's results were validated, it was used to simulate the operation of several HSR and maglev systems along the Orlando-Tampa corridor. The route alignment data were obtained from the Florida Department of Transportation (FDOT).

Task 6: Cost Structure of HSGT Projects (Chapter 7)

The various HSGT corridor studies performed in the U.S. were reviewed to develop a preliminary cost database of main items and to study the cost structure of typical HSR and maglev projects. Some of the corridor studies reviewed are

- The Florida TGV proposal (1988)
- The Florida HSR Corporation proposal (1990)
- The California-Nevada Transrapid study (1990)
- The Texas High-Speed Rail study (1989)
- The TRB Special Report 233 (1991)

Furthermore, several European corridor studies were reviewed. These studies, however, were not used to generate cost data for the U.S. market. It is important to note that there are great uncertainties related to the cost of HSGT systems in North America. No HSR or maglev system has been built, and cost estimates vary greatly among feasibility studies. In fact, even the same study produced different estimates months apart. For instance, the Florida High-Speed Rail Corporation reported in its July 1990 proposal to the State of Florida an estimated total cost of $3.6 billion

($10.3 million per km or $11.1 million per mile) for a 517-km (323-mi) HSR system. These draft cost estimates were reduced to $2.5 billion ($5 million per km or $8.1 million per mile) a few months later in October 1990, for a slightly revised system. Similarly, the cost of the Orlando Maglev Demonstration Project was estimated in 1991 to be about $450 million. In 1992, the estimated cost was raised to $600 million. There are reports today that the newest estimates have further risen sharply by over 20% compared to the cost estimates made in 1992.

Both the Orlando Maglev Demonstration Project and the Texas TGV Project were approved for construction by Florida and Texas authorities, respectively. Detailed cost estimates were requested from the two companies in charge of these projects. Understandably, this effort was not successful due to the confidentiality surrounding both projects.

### Task 7: Cost Estimation Procedure (Chapter 8)

The overall structure of a computerized procedure to produce quick and efficient preliminary capital cost estimates of HSGT projects is outlined. The procedure relies on a database software to compute capital costs. A sample microcomputer model was developed to illustrate the procedure. The capital cost section of the sample model was developed using dBase IV, which is one of the best known and most feature-rich database software. A spreadsheet software was used to write programs to estimate operating costs based on the information provided in Chapter 7. Because most operating costs can be considered uniformly distributed along the route, there was no need for a segmental-type analysis and therefore a database software was not necessary.

The capital cost model is based on a clustering method and a coding system. Items are grouped into greater project units. For example, an HSR track consists of rail, ballast, subballast, ties, and fasteners; maglev electrification includes power supply, substations, control power, electric switches, and power feeders. The coding system is a hierarchical classification method (tree structure), similar to the method used by libraries for coding books. Each code has several alphanumerical components. Each component is a subgroup of the component to its left. Menus allow successive selections of desired branches until the desired detail level is reached. There is no limit to the database’s level of detail because the lowest nodes can be broken down still further, and new menus added, when more detailed information is available. The code for future, more specific items can be developed by adding alphanumerical digits to right side of the "parent" code, without modifying the initial digits that are used by the model to locate and manipulate items.

The cost model is menu controlled. Layers of menus are used to select the various components of the system and to store this information in an efficient way. For example, a guideway type that runs from section 800 to section 1,300 of the route will be entered only once. The model will automatically enter the guideway code for all 500 sections of the route; and the guideway cost for each section will subsequently be adjusted by internal programs to reflect the work condition, soil type, and location of that section.

After all the project's capital items are selected, the model generates a large file where each record (row) represents a route segment and each field (column) represents a cost item of that section. This generated file includes only the alphanumerical codes of selected items. In the final step, the model interacts with a cost database and generates a new file by replacing each code with its corresponding value from the cost database. The resulting file contains all the cost items for all route sections. Prewritten commands are used to produce all types of useful cost summaries.

### Task 8: Conclusions and Recommendations (Chapter 9)

The simulation results are presented, as well as a general comparison of the performance and cost of the various HSR and maglev systems. Internal programs that can enhance the operation of the cost model are outlined, and steps needed to develop and maintain a national unit cost database are described. Recommendations are formulated that call for the development of a uniform coding system for the various items and the need for a structured way to estimate and report item costs in feasibility studies. A more detailed description of item costs makes it easier to adjust them to other projects.

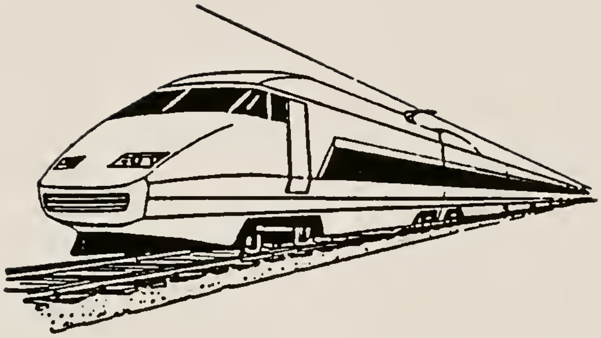
# CHAPTER 2
# HIGH-SPEED RAIL AND MAGLEV SYSTEMS

This chapter provides a description of the various HSR and maglev systems. The emphasis is on operational systems and systems certified as operationally ready. Two of the technologies considered are illustrated in Figure 2-1.

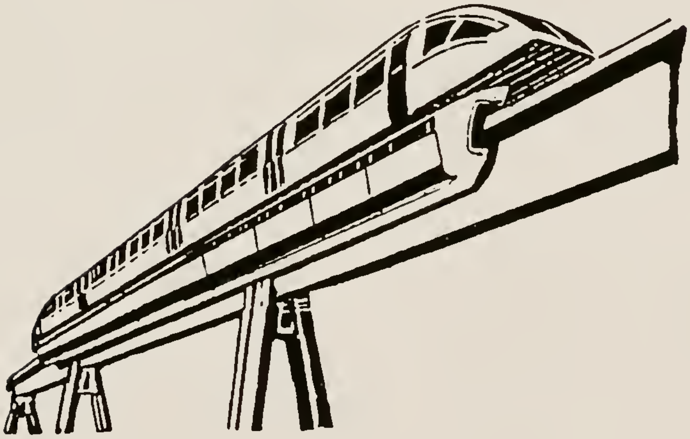
## The Japanese Bullet Train

### Implementation

Japan was the first country to develop a high-speed train, known as the Bullet Train or Shinkansen, as a way to improve mobility between its densely populated cities. Japan, similar to other Asian countries, has a very high population density, a growing transportation demand, and already saturated transportation facilities. The Japanese government subsidized the development of the Bullet Train because it responded to specific needs such as energy efficiency, nonpolluting electric power, and high line capacity. Furthermore, the construction of new HSR lines were seen as an effective means of developing secondary urban areas for residential and industrial relocation, thereby relieving the demographic and industrial growth in major cities (Roth, 1990; Hagiwara, 1977).



French TGV HSR



German Transrapid Maglev

Figure 2-1: Illustrations of HSR and Maglev Systems
Source: Petersen, 1985.

The first Bullet Train service was initiated in 1964. It provided a link between Tokyo and Osaka. The top speed of the first generation of Bullet Trains did not exceed 218 km/h (136 mph). The average speed was much lower because of route alignment and in order to reduce energy consumption and noise emission. In later years, lighter and more powerful Bullet Trains in addition to improved alignment and extensive use of noise barriers permitted operations at significantly higher speeds. The travel time on the Tokyo-Osaka line was gradually reduced from the initial four hours to about two and a half hours, achieved with the new Super Hikari Bullet Train.

### Technology

Bullet Trains have a modular structure, which means that cars can be added or taken off a train. All cars are self-propelled, and therefore they can be added to a train without affecting the train's acceleration rates. Bullet Trains run on conventional standard gauge track of 1.435 m (56.5 in). Rails are continuously welded to eliminate the "ticking" sound. The propulsion is based on electric power supplied through an overhead catenary power distribution system. The most recent Super Hikari, Series 300 Shinkansen, is capable of a top speed of 270 km/h (168 mph).

### Infrastructure

All Bullet Train lines are grade-separated, built on exclusive right-of-way. Japan's difficult terrain and limited right-of-way have required the construction of numerous tunnels and bridges. For instance, the 320-mile line between Tokyo and Osaka has about 66 tunnels and over 3,100 bridges, accounting for almost one-third of the distance; and the rail link to the north island of Hokkaido required the construction of a $5.6 billion 32-mile Seikan Tunnel and other special structures.

### Evaluation

Right after the Tokyo-Osaka Shinkansen line was opened, it experienced a phenomenal increase in ridership. It is still operating at a profit. Additional Bullet Train lines serving less populated cities were gradually added to the rail network. The operations of some of these newer lines are still subsidized by the government. Japan has today over 1,300 miles of high-speed tracks, and more lines are planned. The Bullet Train lines carry over 125 million passengers annually. They have a perfect safety record and their on-time arrival rate is about 99% (Vranich, 1991).

## The French TGV

### Implementation

The Paris-Lyon route is France’s most important and heavily travelled corridor. In the early 1960s, the double-track rail line that served the two cities was near saturation, but the demand was rising steadily. To provide additional capacity, the French government decided to construct an entirely new line, exclusively dedicated to carrying passengers at high speed. The new line starts on the outskirts of Paris and Lyon and utilizes existing lines and stations within the cities. The Paris-Lyon line started operation in 1981, and the full 439 km (273 mi) segment was completed in September 1983. The French HSR technology, known as the TGV (Train a Grande Vitesse), significantly outperforms the Japanese Bullet Train and remains to date the fastest rail system in commercial operation. The TGV reached a speed record of 515 km/h (320 mph) on May 18, 1990.

Construction work on another line to serve the French Atlantic seaboard from Brest to Hendaye started in 1985. The TGV Atlantic line became fully operational in 1991. While the Paris-Lyon line has no tunnels, the TGV Atlantic line has 7.6 km (4.75 mi) of tunnels and 3.5 km of viaducts (Ross, 1990; Chambron, 1986). Additional lines crossing the French borders to Belgium, Germany, and Great Britain through the Eurotunnel are near completion. The TGV North will reduce the 2 hour 25 minute trip between Paris and Brussels to 1 hour 30 minutes, and the 4 hour 50 minute trip between Paris and Cologne to 2 hours 50 minutes. The travel time from Paris to London will be reduced by more than half, to about three hours. The rolling stock for these new lines is based on the TGV-A. The expected top operational speed will be increased to 320 km/h (200 mph). The Eurotunnel trainsets, called the Transmanche Super Train (TMST), will consist of 18 passenger cars constructed with composite materials. Each TGV-TMST trainset is designed to carry about 800 passengers.

## Technology

The first TGV rolling stock developed for the Paris-Lyon line is known as the TGV-SE (southeast). The TGV-SE operates at a maximum commercial speed of 270 km/h (168 mph). Each TGV-SE trainset is composed of 10 units and carries 386 passengers. A new generation of rolling stock known as the TGV Atlantic or TGV-A was developed for the Atlantic line. The TGV-A incorporates several technical advances, the most important being the reliance of synchronous, self-commutating traction motors. The three-phase synchronous motors are lighter, more powerful, and more energy efficient than the DC asynchronous motors used in the TGV-SE. They are also easier to maintain because they do not contain a commutator, which requires reprofiling roughly every 300,000 km (187,500 mi) (La Vie du Rail, 1990). In a synchronous motor, the role of the rotor and stator are reversed, and the rotor (field coil) rotates at the same speed as the revolving field generated by the stator (stationary part or armature). The synchronous motor can also be used as a fail-safe electric brake by reversing its operation to function as a generator.

Other improvements in the TGV-A rolling stock include a more aerodynamic design, two additional passenger sections per trainset providing a total seating capacity of 485, a novel air-sprung suspension that provides an inter-car damper mechanism, a microprocessor-controlled wheel slip prevention mechanism, a microprocessor-based diagnostic system, an improved pantograph design to collect current from the catenary above, improved disk brakes, and fail-safe electric brakes (eddy-current) that operate independently of the power supply (Lacote, 1986). Only eight synchronous motors (maximum power output is 1,100 KW [1475 HP] per motor and 8,800 KW [11800 HP per trainset) are used in the TGV-A. The older, smaller-size TGV-SE trainset is powered by 12 asynchronous motors (maximum power output is 580 KW [778 HP] per motor and 6960 KW [9340 HP] per trainset). The TGV rolling stock has a nonmodular trainset design. Each trainset is composed of a fixed set of articulated passenger cars, propelled by one power car at each end (push-pull operation). A fixed formation trainset has the advantages of improved aerodynamics, lower noise and vibration levels, and enhanced riding comfort (Lacote, 1986). The TGV-SE trainset is composed of 10 units: an articulated section of eight passengers cars (trailers) and two power cars. The trainset configuration is described as 1P-8T-1P where "P" stands for power car and "T" for passenger trailer. The TGV-A has a 10-section, articulated trailer and two power cars. The trainset configuration is therefore 1P-10T-1P. The TGV-North and TGV-Texas have both a 1P-8T-1P configuration, and the TGV-TMST designed to cross the Eurotunnel has a 1P-18T-1P configuration. The TGV-Texas trainset is based on the TGV-A technology, is capable of operating at 320 km/h (200 mph), and has 317 passenger seats (USDOT, 1991c).

### Evaluation

The Paris-Lyon TGV line has attracted more ridership than predicted. It is unanimously considered to be a huge technical and commercial success as illustrated by the profit margin shown in Figure 2-2. By 1990, the TGV-SE line had carried over 100 million passengers without any fatal accident. The line continues to operate at a substantial profit. Revenues from the TGV-SE line paid back the infrastructure cost in ten years instead of the originally projected fifteen. All the new TGV lines are expected to operate at profit, although their rate of return is expected to be smaller than that of the TGV-SE line. The TGV rolling stock has earned a reputation of reliability, dependability, energy-efficiency, and safety. The French National Railways' master plan calls for the building of a 2,000-mile network of 14 new TGV lines by 2015 (La Vie du Rail, 1990).

## The German ICE

### Implementation

Ten years after the TGV started operation on the Paris-Lyon line, the Germans introduced the ICE train (Intercity Express) in 1991. The first ICE operation was on newly constructed Stuttgart-Mannheim and Hanover-Wurzburg lines. These two lines and the Cologne-Frankfurt line (scheduled for completion in 1996) will provide 800 km (500 mi) of new ICE track. In addition, the German Federal Railway (DB) is in the process of upgrading 3,200 km (2000 mi) of existing tracks for

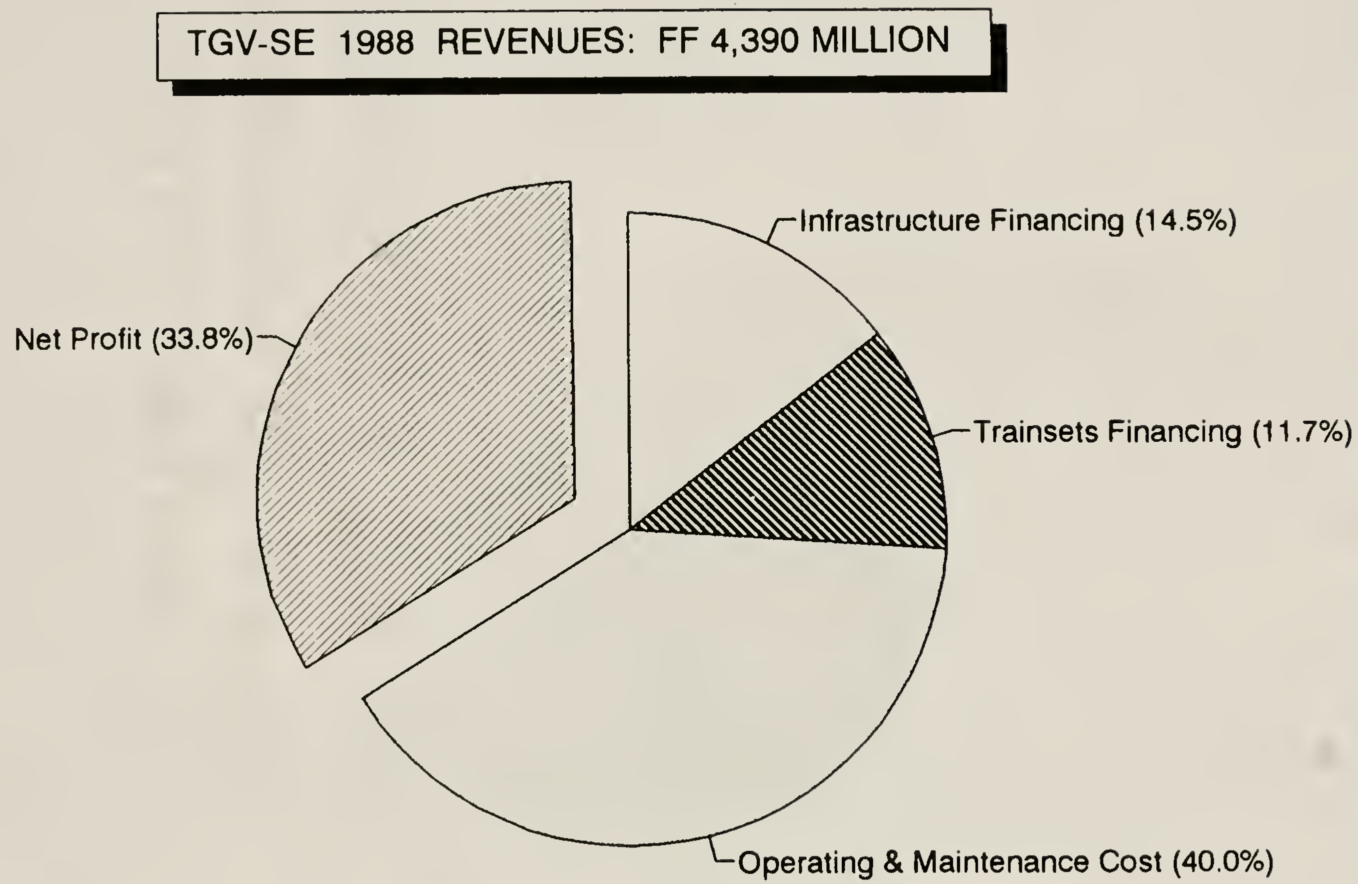


Figure 2-2: TGV-SE Distribution of 1988 Operating Revenues
Source: Roth, 1990.

ICE standards. The ICE trains operate at a top speed of 250 km/h (156 mph) on new lines and 200 km/h (125 mph) on upgraded lines.

## Technology

The ICE power car uses advanced three-phase asynchronous motors designed without wearing parts. The ICE trains are certified for maximum commercial speeds ranging from 250 km/h to 300 km/h. The traction and braking systems of the ICE are largely computer controlled. The train is capable of regenerative braking that recovers energy during the braking phase and returns it to the overhead power supply network. European countries use different power supply environments for their rail system. The ICE-M is designed to automatically identify the voltage and frequency being provided by the overhead wires and transform it to the required voltage.

The ICE passenger cars are manufactured with an aluminum body shell that provides significant weight saving and reduced dynamic loading. Aluminum is also employed in the major components of the power car such as the transformers and the gears housing. The ICE train has the lowest drag coefficient of all HSR systems due to a streamlined design, smooth outside surfaces, and flush-fit windows and doors. It is also quieter than the TGV or Bullet Train because it is equipped with wheel noise absorbers and selected components are covered with noise-absorbing materials. The ICE cars are pressurized and the inside pressure is regulated by the air conditioning system (ICE, 1992).

Unlike the fixed formation of a TGV trainset, the ICE has a modular design which provides the flexibility to adjust the number of cars in a train to suit the demand. An ICE train has a power unit on each end and can comprise any number of passenger cars between 6 and 14. The ability to safely run trains of various lengths requires sophisticated communication and signaling systems. This is insured by heavy reliance on computer chips and optoelectronic (fiber optics) data links. The ICE is also equipped with a comprehensive computerized diagnostic system that checks all the equipment throughout the train. Each microprocessor subsystem possesses a self-diagnostic capability, and communicates with a central diagnostic unit that receives, analyses and stores all relevant reports. Diagnostic reports are displayed on a screen located in the power unit. Should a malfunction occur, the diagnostic system identifies the cause and displays it on a special screen in view of the driver, and simultaneously recommend an action to be taken (ICE, 1991).

The ICE uses three braking systems designed to improve passenger comfort and reduce maintenance cost. First, a regenerative brake is applied, then an eddy-current brake based on electromagnetic attraction that acts independently of wheel/rail adhesion is used, and finally, a disk brake is applied if necessary (Rosen, 1989).

## Infrastructure

The cost per mile of a new ICE line is two to three times that of TGV lines. There are many reasons for this cost disparity, the most important being the following:

- The ICE uses slab tracks that allow mixed traffic with priority freight trains. The TGV tracks are ballasted and used for exclusive passenger use. The TGV weight is limited to 17 tonnes per axle (18.7 tons per axle).
- The signals and communications on the ICE lines must accommodate mixed traffic and variable size ICE trains, while only fixed TGV trainsets having exactly the same number of cars per trainset operate on TGV lines.
- The topography of the ICE lines is more difficult than that of the TGV lines. Furthermore, because the ICE line must accommodate freight trains with less powerful tractive power, grades are limited to 1.25% as opposed to 3.5% for the TGV. As a consequence, the ICE lines required more extensive earthwork, and numerous tunnels and engineering structures.
- German legal system requires public disclosures and public hearings before plans for new rail lines can be approved. This generated 360 lawsuits and 10,700 objections and resulted in years of delay for the ICE lines. The French legal environment makes it easier to acquire right-of-way for a new line. If a rail project is considered by the French government to be "in the

national interest," objections to new lines are legally unable to delay construction work.

### Evaluation

The first ICE line started operation in 1991. It is too early to develop a detailed assessment of the ICE system. All indications, however, confirm that the ICE is a technical and financial success. Ridership the first 100 days were 25% higher than expected, and public support remains strong. The reunification of Germany modified early rail expansion plans. Current plans call for the completion of a new ICE line between Hanover and Berlin by late 1997. Other new and upgraded lines for the ICE system are also planned. German rail experts anticipate a 30% ridership increase in the next few years (ICE, 1992).

## The ABB X-2000 Tilt Train

### Implementation

The X-2000 is a tilt train developed by Asea Brown Boveri (ABB) and first used in commercial operation by the Swedish State Railways (SJ). The purpose of developing the X-2000 was to provide a train that can achieve higher speeds on existing tracks, thus reducing the travel time without the need to build a new line or extensively upgrade existing ones. The X-2000 started operation in 1990, on a line 456 km (284 mi) long between Stockholm and Gothenburg. The travel time was reduced from four and a half hours to under three hours. SJ plans to utilize the X-2000 in other Swedish corridors.

In November 1991, Amtrak signed a deal with ABB and SJ to bring one spare X-2000 trainset to the Northeast Corridor. In February 1993, a X-2000 trainset started a daily roundtrip between New York and Washington; and two months later it began operating between New Haven and Washington (Pope, 1993).

## Technology

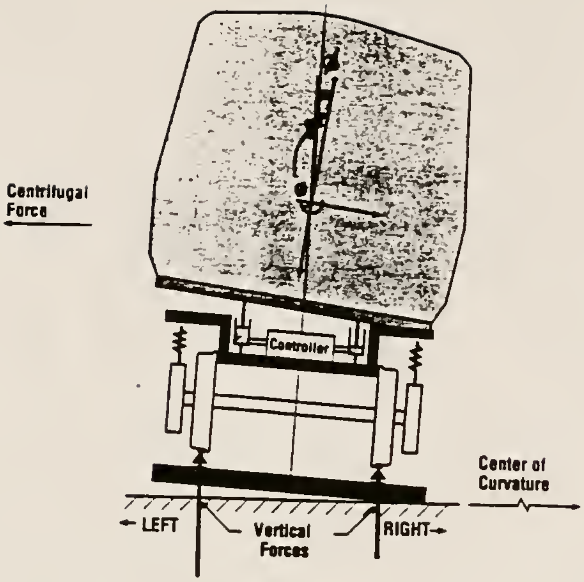
The X-2000 offers an innovative body tilting mechanism and suspension system that enable the train to travel around curves up to 25% faster than a nontilt train. This is possible because the tilt mechanism partially balances the lateral acceleration caused by traveling around a curve as explained later in Chapter 5. Lateral acceleration reduces comfort and must not exceed the allowable limits set by FRA.

Tilt control can be passive or active. A passive tilt mechanism is caused directly by the unbalanced lateral forces acting at the car body center of gravity. The Spanish Talgo Pendular train is an example of this technology. The X-2000 employs a more complex active tilt mechanism. The advantages of an active tilt is that the tilt operation can be controlled and monitored. The tilt of passenger cars is mechanically actuated and controlled by a microprocessor that activates sequentially the tilt mechanism of each car to insure a comfortable transition. A computer located in each car monitors the tilt operation and performs redundant checks. The active-tilt technology principles are also used by the Canadian LRC and the Italian ETR train systems.

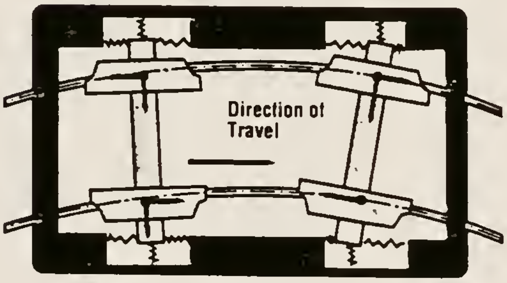
The active tilting mechanism on the X-2000 is adjusted to cancel about 70% of the unbalanced lateral acceleration. It is disabled at low speeds. The lateral acceleration is measured by two sensors mounted in the center and lead truck and signal the microprocessor to activate the tilt in passenger cars. The power car is not equipped with a tilt mechanism to ensure a good alignment between the pantograph and the catenary line. In addition to active tilt, the X-2000 uses a flexible suspension system that allows axles to move independently of the rigid truck frame and keeps wheels aligned with the track as illustrated in Figure 2-3. The flexible suspension reduces the wheel rail forces and lateral-to-vertical force ratios while negotiating curves (USDOT, 1991a).

The X-2000 trainset currently being tested in the U.S. consists of one power car and five or six passenger cars. A configuration with two power cars can have up to 12 intermediate passenger cars. Each power car carries four AC asynchronous traction motors, capable of delivering 3200 KW (4300 HP). The motors are light and designed for low maintenance. The X-2000 top commercial speed is 240 km/h (150 mph).

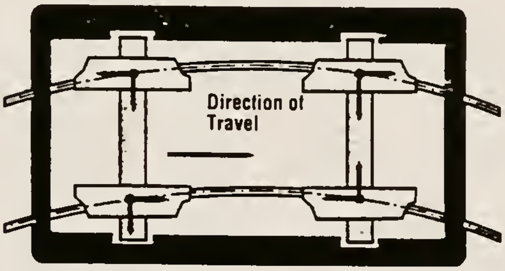
The coach body is made of a steel frame. Modular construction is utilized and components are replaced via an opening in the roof. The floor is made out of wood and is isolated from the steel frame to reduce noise. Side windows are multilayer safety glass, designed to minimize the risk of



Coach Body Tilt System of the X-2000 Train



Self-Steering Trucks of the X-2000 Train



Conventional Steering Trucks

Figure 2-3: X-2000 Tilt Body and Self-Steering Trucks
Source: USDOT, 1991a.

injury during derailment. The X-2000 has three braking systems: a disk brake, a regenerative dynamic brake, and an electromagnet brake.

### Infrastructure

The main advantage of the X-2000 is that it can operate on existing tracks at higher speeds. This can be an attractive option when right-of-way for new lines or improved alignment is difficult to obtain or excessively expensive. The X-2000, however, requires an electrified line to deliver the required power. Its top speed on tangent sections is over 20% lower than that of TGV or ICE.

### Evaluation

The operation of the X-2000 in Sweden has been successful. The trial runs on the Northeast corridor have just began. They have, nonetheless, generated positive reactions from the public and the media. Amtrak is planning to replace its Metroliner fleet with 26 high-performance trains. A decision has not yet been made on the technology, although the X-2000 seems to be a good candidate. ABB has offered to build the trains at its plant located in the state of New York. Transportation officials in Michigan, Illinois, Southern California and the Pacific Northwest have also expressed interest in the X-2000 (Pope, 1993).

## The German Transrapid Maglev System

### Implementation

Transrapid maglev is a new generation of ground transportation systems. Although no maglev system has been implemented in commercial operation anywhere in the world, Transrapid has extensively been tested on a 31.5 km (20 mi) single-track guideway built in the German Emsland region near the Dutch borders.

In 1992, the German government certified the Transrapid-07 system as operationally ready, and initially considered implementing the Transrapid technology on a 50 km (31 mi) line that links the airports of Bonn and Duesseldorf. The German reunification, however, made the ICE Berlin-Hamburg line a much higher priority, especially that Berlin replaced Bonn as the capital of Germany. Other Transrapid feasibility studies involved the Hamburg-Hannover and the Essen-Bonn corridors, but no decisions were made in either case.

In the United States, the Transrapid system was proposed to operate on a line between Las Vegas, Nevada and Anaheim, California. In 1990, Bechtel submitted a proposal for a franchise to build and operate the system. The financing of the project was to be assumed by C. Itoh & Co., a major Japanese company. The slowdown in California's economy, however, caused the project to be canceled.

Privately financed Transrapid demonstration projects are planned in both Orlando, Florida and Pittsburgh, Pennsylvania.

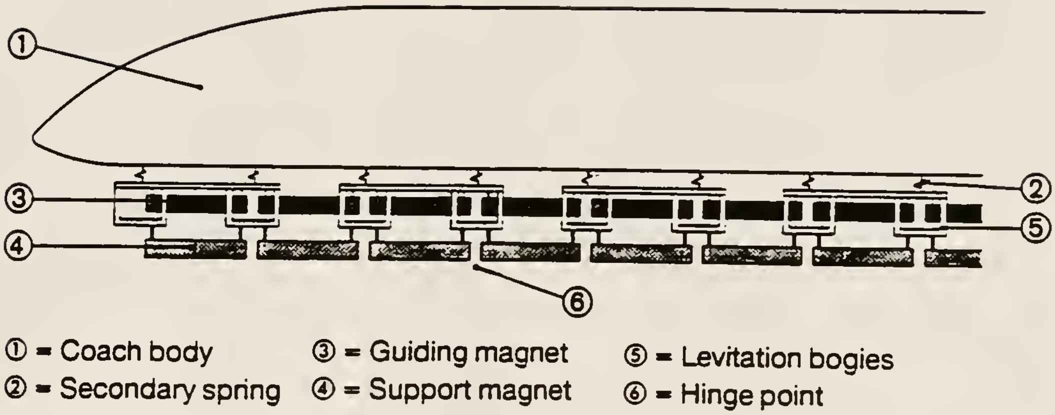
The engineering study phase is at an advanced stage in Orlando. However, the ability to finance these projects with private funds remains uncertain due to vast fluctuations in capital cost estimates.

## Technology

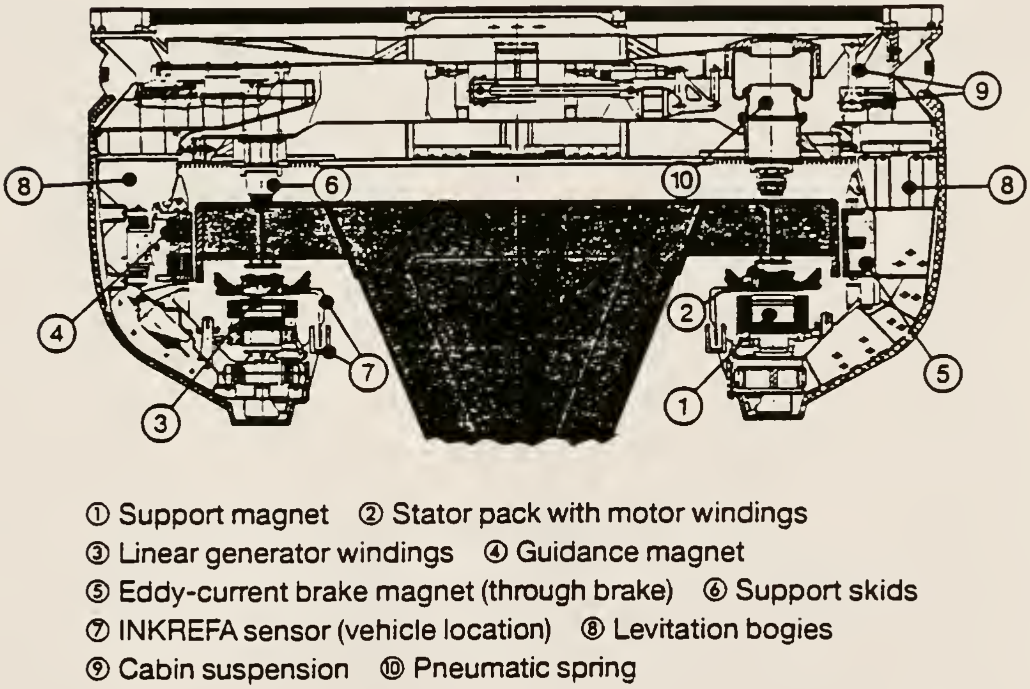
The development of the Transrapid technology was sponsored by the German Ministry of Research and Technology. Leading German industrial companies, the German National Railways, and Lufthansa airlines participated in this effort.

Transrapid is a maglev train designed for speeds of 400 km/h to 500 km/h (250 mph to 310 mph) and capable of climbing up to 10% grades. The system requires a completely dedicated guideway that can be either elevated or near grade. Transrapid vehicles levitate by attractive electromagnetic suspension (EMS) and are propelled by linear induction. Transrapid operation involves no contact between the guideway and the vehicle; which causes less wear, less maintenance, and less noise than HSR systems (U.S. House of Representatives, 1990).

Transrapid vehicles levitate by using the forces of attraction between individually controlled electromagnets arranged under the floor of the vehicle and ferromagnetic rails (stator packages) installed under the guideway as illustrated in Figure 2-4. A redundant electronic control system insures a constant levitation gap of 8 mm (0.315 in). Every section of the vehicle is equipped with 15 support magnets and 13 guidance magnets (Meins and Ruoss, 1979).



Side View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① Support magnet
② Stator pack with motor windings
③ Linear generator windings
④ Guidance magnet
⑤ Eddy-current brake magnet (through brake)
⑥ Support skids
⑦ INKREFA sensor (vehicle location)
⑧ Levitation bogies
⑨ Cabin suspension
⑩ Pneumatic spring

Cross Section

Figure 2-4: Transrapid Support and Guidance Systems
Source: Meins and Ruoss, 1989.

Independent suspension is provided for each magnet. A synchronous long-stator linear motor is used to propel and brake the train. Thrust is controlled by changing the intensity and frequency of the three phase current. Changing the polarity of the electromagnetic field causes the motor to function as a generator which brakes the vehicle without physical contact (Ciessow et al., 1989).

All critical components are error tolerant and designed with a high functional redundancy. Redundant systems are also used for levitation and guidance (USDOT, 1991b). Operational safety is enhanced by energizing only the section of the guideway on which the train is traveling. Derailment is not possible because the suspension system wraps around the guideway. Transrapid signal and control systems are fully automated. In an emergency situation, brakes can be actuated from the central control unit.

The noise emission of Transrapid is significantly lower than that of HSR systems. Transrapid consumes 30% less energy than a high-speed train traveling at the same speed. Energy consumption, however, rises rapidly at higher speeds because of air resistance that increases with the square of the speed.

Transrapid vehicles are constructed with sandwich-type light alloy plates. The vehicle's shell structure is made of high-strength aluminum framing that provides high structural stiffness. A glass-fiber plastic shell is used in the top part of the vehicle noise and the cylindrical part of the coach body. The side windows consist of two panes individually glued to the coach body to improve sound and heat insulation. A Transrapid trainset can consist of 2 to 10 sections. A 2-section trainset has a capacity of 156 passengers, a 10-section trainset can carry a maximum of 1,060 passengers (Gaede and Kunz, 1989).

### Infrastructure

Transrapid guideway can be made of either steel or reinforced concrete. The guideway consists of sectional beams of 25 m to 50 m (82 ft to 164 ft) long. Typical elevated guideways are about 4.5-m (15 ft) high. The supporting concrete columns tested on the Emsland track have either A or H shape.

The ability of Transrapid to climb up to 10% grades can reduce the earthwork cost and the need for tunnels, bridges and other special structures. On the other hand, the strict construction tolerance adds significantly to the guideway cost. For instance, guideway foundations in Florida can be very expensive in a wetland or unstable-soil environment. Impacts of temperature variations have also to be accounted for within the tolerance limits of the guideway design.

### Evaluation

The Transrapid system has only been operational on a test track located in Germany and in international exhibitions. There are no information available to evaluate the system in revenue service operations.

## Japanese HSST Maglev System

The HSST (High-Speed Surface Transportation) maglev system is being developed by Japan airlines. HSST vehicles levitate using attractive electromagnetic suspension (EMS) similar to Transrapid. However, the propulsion system is provided in the vehicle by linear induction motors instead of the guideway, which makes the HSST less suitable for very high speeds.

The development of the HSST technology began in 1975. The first prototype (HSST-1) was tested in 1977. The second prototype (HSST-2) was introduced in 1978. It has eight seats and was designed for a top speed of 100 km/h (62 mph). The third prototype (HSST-3) has 48 seats. It was demonstrated at the World Exhibition in Vancouver. The Vancouver track was only 450 meter (1477 ft) long which allowed a maximum speed of 40 km/h (25 mph). The latest prototype (HSST-4) is designed for a top speed of 200 km/h (125 mph) and accommodates 70 passengers.

The HSST-3 achieved a reliability factor of 99.96% during operation at an exposition in Japan (Vranich, 1991). The HSST-4 was demonstrated in 1988 at an exposition near Tokyo. A proposal to build a HSST system in Las Vegas has been approved. If built, the HSST will use small and lightweight vehicles. It will function as a downtown people mover and operate at a moderate speed.

The HSST is being viewed as a fast short-distance transportation system suitable for urban environments. It is primarily marketed as a noiseless, low vibration people mover system. It can operate on small turning radius and the system's stations can be integrated with buildings and parking facilities.

## The Japanese MLU Maglev System

The MLU maglev system is being developed by the Japanese National Railways (JNR). The research begun in 1962. Ten years later a prototype was demonstrated on a 480-m (1575-ft) long test track. A research center and an test track were subsequently built on the island of Kyushu near Miyazaki. The test track was converted in 1979 to a U-shape guideway that contains coils for propulsion and guidance in the sidewalls and coils for suspension on the horizontal surface.

The MLU vehicles use electrodynamic suspension (EDS) for levitation. Propulsion is provided by synchronous linear motors. The vehicle is levitated by repulsive forces between the magnetic field in the guideway and the superconducting coils of the same polarity in the vehicle's underside as shown in Figure 2-5. Superconducting dynamic levitation is effective only at speeds above 100 km/h (62 mph). At lower speeds, the vehicle is supported and guided by pneumatic wheels that retract when the train's speed reaches 160 km/h (100 mph). The vehicle levitates several inches above the guideway.

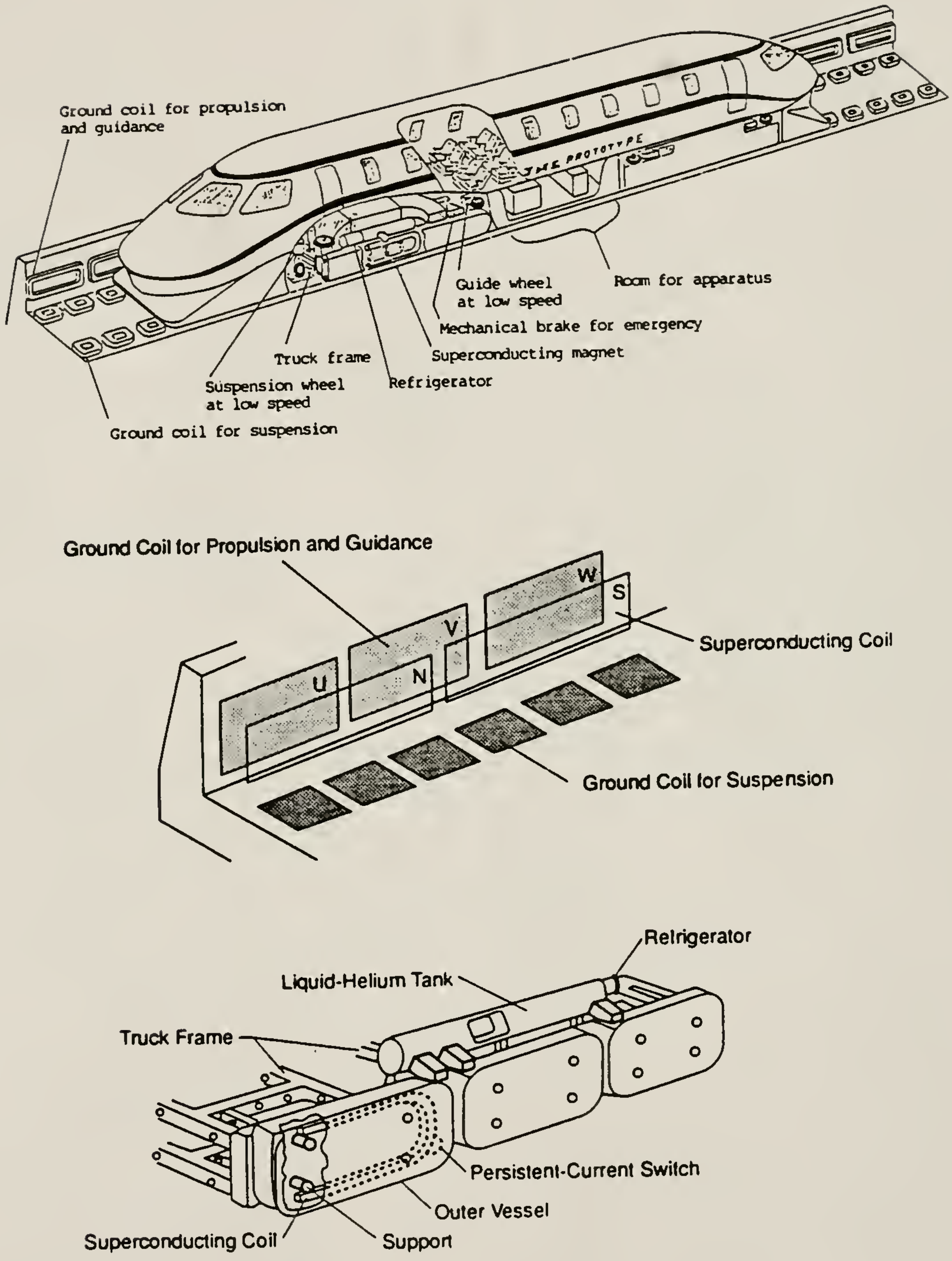

Ground coil for propulsion and guidance
THE PROTOTYPE
Guide wheel at low speed
Room for apparatus
Mechanical brake for emergency
Superconducting magnet
Truck frame
Suspension wheel at low speed
Refrigerator
Ground coil for suspension
Ground Coil for Propulsion and Guidance
W
S
V
U
N
Superconducting Coil
Ground Coil for Suspension
Refrigerator
Liquid-Helium Tank
Truck Frame
Persistent-Current Switch
Outer Vessel
Superconducting Coil
Support

Figure 2-5: Japanese MLU002 Maglev Vehicle and Guideway
Source: Kyotani and Tanaka, 1986.

The MLU001 prototype has a modular structure. A three-car MLU001 trainset has a mass of 33 tonnes (36.3 tons) and is 29 m (94 ft) long. Each car has eight superconducting coils used for suspension, guidance and propulsion. The MLU001 with a three-car configuration reached a speed of 350 km/h (218 mph) on the Miyazaki test track.

The MLU002 prototype has six superconducting coils per side. It has a mass of 19 tons, accommodates 44 passengers and is designed for a top speed of 420 km/h (260 mph) (Johnson et al., 1989). The MLU002 test runs caused component failures, and strong electromagnetic fields were measured. This prototype was damaged by fire in October 1991. The JNR, however, has decided to build a new prototype, the MLU002N, and a new 43-km (26.7-mi) long test track (Vranich, 1992; New Technology Week, 1993). A commercial version of the MLU002 may have as many as 14 cars per trainset. Nonetheless, it will take years before all concerns are answered and the commercial version is approved for revenue service.

## The American Maglev Systems

Basic theoretical work on maglev concepts were conducted at the Brookhaven National Laboratory in the early 1960s. Two researchers of this laboratory, James Powell and Gordon Danby, developed and patented the "null-flux" system that is capable of high lift-to-drag ratio and stiff restoring forces. This null-flux system consists of placing the vehicle magnets between two guideway coils. No induced current is generated if vehicle magnets are centered between the coils. Deviations from the center position generate opposing currents that act as a restoring force (Powell and Danby, 1969; Danby et al., 1974). The maglev systems being developed in Japan have adapted some of the features described by Powell and Danby. A group formed by these researchers have recently proposed a 32-km (20-mi) long demonstration maglev system between Kennedy Space Center and Port Canaveral (Speedlines, April 1993).

In late 1960s, the use of superconducting magnetic suspension for a rocket operating in an evacuated tunnel was examined by the Stanford Research Institute and Rockwell. Subsequently, several technologies for maglev vehicle levitation were examined by the Stanford Research Institute. The EDS suspension concept was determined as the most favorable (Barbee, 1968).

Ford Motor Company became also interested in maglev technology (Coffey et al., 1969). A study conducted by Ford concluded that attractive suspension provides a higher lift-to-drag ratio than repulsive suspension. The attractive system has a low magnetic drag, but also a low tolerance for track misalignment (Johnson et al., 1989). A conceptual design of an EDS maglev system that can carry 80 passengers was developed, but no further detailed analysis was pursued.

Important theoretical research was conducted at the Massachusetts Institute of Technology (MIT) during the 1970s. Several patents resulted from this effort. A conceptual maglev system called the Magnetplane was developed by two MIT researchers: Henry Kolm and Richard Thornton. The innovative feature of the Magnetplane is its self-banking ability due to a 0.3-m (1-ft) air gap and a semicircular guideway design as shown in Figure 2-6. Magnetplane was demonstrated with a 1/25th-scale model operating on a guideway 120 m (400 ft) long. In 1975, the federal government terminated funding for all HSGT research. This action stopped most of the maglev research being conducted at MIT, Ford, Boeing and other companies and laboratories. In 1991, as part of the government's maglev initiative, maglev research was resumed at MIT and other laboratories. The research focus is related to system concept definition for vehicles, guideways, suspension and propulsion.

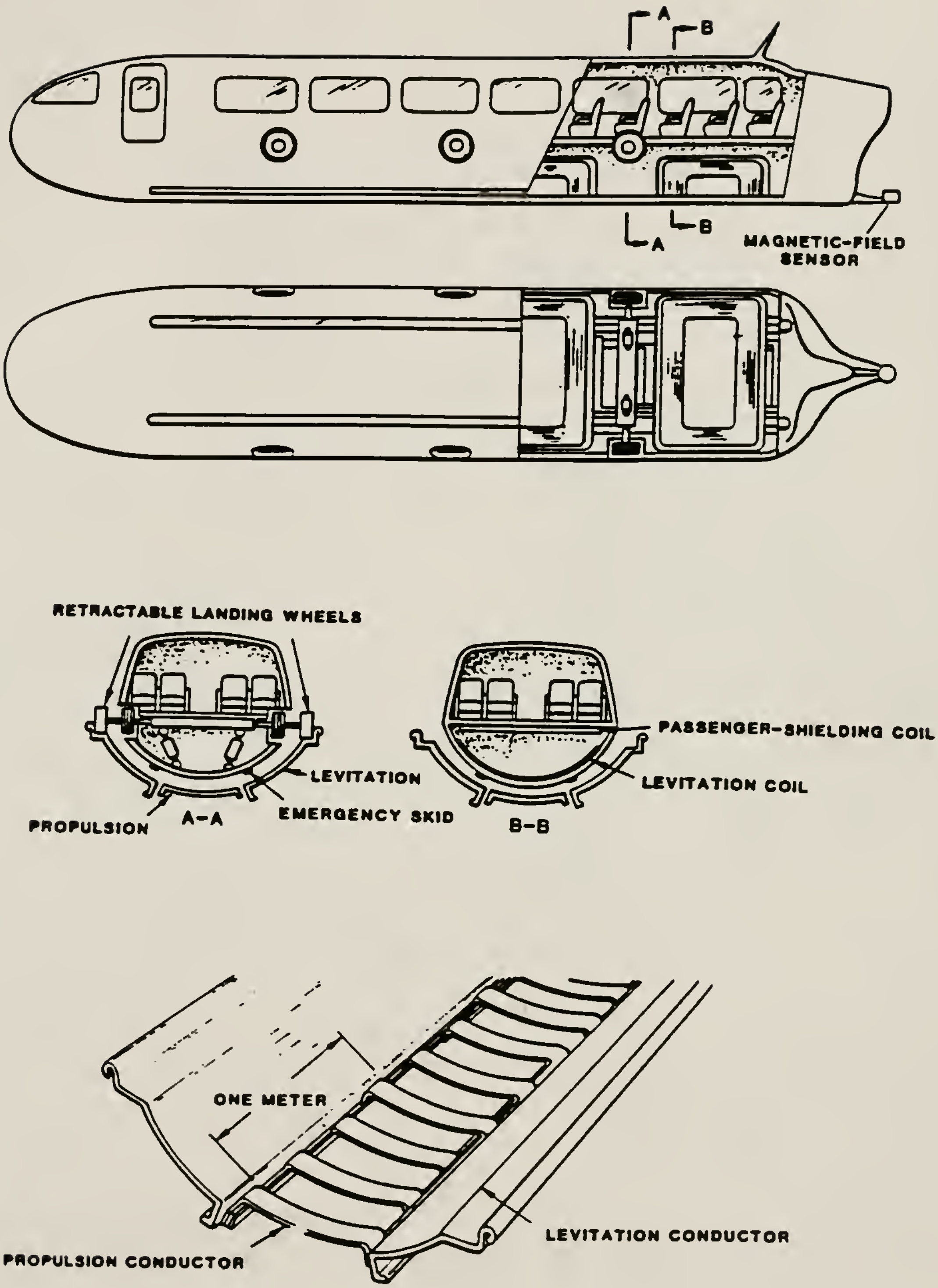


Figure 2-6: Magnetplane Vehicle and Guideway
Source: Johnson et al., 1989.

# CHAPTER 3
# COMPARISON OF HSGT SYSTEMS

The comparisons presented in this chapter are between conventional and high-speed trains, High-speed trains and maglev systems, EMS and EDS maglev levitation technologies, and tilt and nontilt trains.

## Conventional and High-Speed Trains

High-speed rail involves more than fast trains. Additional technological advances are necessary. The main characteristics that distinguish HSR from conventional rail are described in the following paragraphs.

### Electric Traction

Diesel engines are heavy and incapable of high acceleration rates (TRB, 1991). Diesel-electric and turbine-electric motors that generate electricity on board also add to train's mass and maintenance cost (they can, however, be used as a temporary solution until line electrification is completed.) The most appropriate traction should draw current from a catenary system instead of generating electricity on board. Synchronous and asynchronous three-phase electric motors have the highest power to weight ratio and are therefore the preferred engines for HSR systems. The train's low weight is also important for braking performance and for reducing dynamic loading on the rails.

### Integrated Braking systems

High-speed trains are typically equipped with three braking systems. The first is a regenerative braking feeding power back to the electric line overhead, the second is an eddy-current brake based on attractive electromagnetic forces, the third is a set of disk brakes. The regenerative and eddy-current brakes are used in most cases because they do not involve physical contact and therefore reduce wear and maintenance. Disk brakes are used mainly in emergency cases.

### Streamlined Shape

At high speeds air resistance becomes the dominant resistive force. A streamlined shape and articulated passenger cars are used to reduce drag and provide a stiff and stable design. High-speed trains are also equipped with primary and secondary suspensions to improve the ride quality. The articulated design of passenger cars further reduces the vibration of individual train sections. Noise absorbent material is used in the car body and component design to reduce interior noise. Passenger cars are usually pressurized if the route includes tunnels. Amenities such as comfortable seats, restaurant and conference coaches, large-view windows, convenient luggage facilities, high-quality service, convenient and automated reservation system, on-board telephones, and computer links are provided to attract business travelers away from airlines.

## Safety Features

The impressive safety record of HSR systems in service operation is due to a number of advanced safety features. Some of these features are a fail-safe and automatic train control (ATC) system that continuously monitors train operation and automatically stops the train if the operator commits an error or if an obstacle is detected on the track; advanced signalization controlled by redundant processors and detectors; automatic block signaling designed to maintain a safe distance between trains to prevent collisions; and electronic components with self-diagnose capability that are programmed to automatically notify the operator and the control center (via display and warning sound and light) of defective or malfunctioning parts.

## Track Design

Although HSR systems use standard track gauge and are capable of operating on existing tracks, they can only reach their maximum speed on new tracks designed for high-speed operation. As previously stated, the track should be equipped with overhead catenary and advanced signalization. Track alignment should be as straight as possible and completely grade separated. Steeper grades, however, can be allowed because the powerful electric motors and the stored kinetic energy (function of speed) permit climbing up to five percent grades. Conventional diesel-powered trains are generally limited to one percent grades.

## Maglev and High-Speed Rail

The primary advantage of maglev technology is that the propulsion, suspension, and guidance of the vehicle are achieved by magnetic forces without physical contact. Traction derives from electromagnetic forces that are generated without moving mechanical components. The contactless operation causes less wear and noise, and lower frictional forces; making the system suitable for very high speeds (Magnet Schnellbahn, 1991). Other important advantages of the maglev technology are the lightweight aluminum or composite car body which reduces weight and improves acceleration and climbing ability (train's weight is also reduced because the stator wires are located on the guideway instead of the vehicle); higher banking angles allowing higher speeds on curves; advanced electronics used in the guidance, communication, monitoring, braking, and automated control modes; lower energy consumption than HSR at comparable speeds; and better distribution of dynamic loading over the guideway (vehicle weight is distributed over wide magnets instead of the small contract area between HSR wheels and rails).

The primary disadvantage of maglev technology is that it requires a costly and exclusive guideway, and therefore cannot use existing tracks and existing stations in urban areas. Providing a new access to urban areas can be very expensive. While HSR systems can operate on conventional tracks at lower speeds, maglev passengers are required to transfer to complete their trip on existing rail lines. This is the main reason why maglev systems are being proposed primarily to link nearby airports (Johnson et al., 1989). Another disadvantage of the maglev technology is that maglev systems have only been operational on test tracks and in international expositions. Furthermore, the EDS maglev system is still in the developmental phase. Because no maglev system has been implemented in revenue service, the infrastructure cost and operational expenses cannot be estimated with any reasonable degree of accuracy. Maglev trial runs on test tracks are infrequent and at speeds lower than the maximum speed. The reliability of maglev vehicles and infrastructures in a full-schedule revenue service remains to be proven (USDOT, 1991b).

## EMS and EDS Maglev Technologies

Maglev vehicles are levitated either by attractive electromagnetic suspension (EMS) or repulsive electrodynamic suspension (EMS) as shown in Figure 3-1. The German Transrapid and the Japanese HSST use the EMS technology. The Japanese MLU and most of the proposed U.S. maglev systems use the EDS technology. Transrapid and MLU propulsion is provide by linear synchronous motors that include field coils in vehicles' underside and active stator windings on the guideway.

Levitation of EMS vehicles derives from the attractive forces between conventional electromagnets placed on the lower portion of the vehicle and a ferromagnetic guideway.

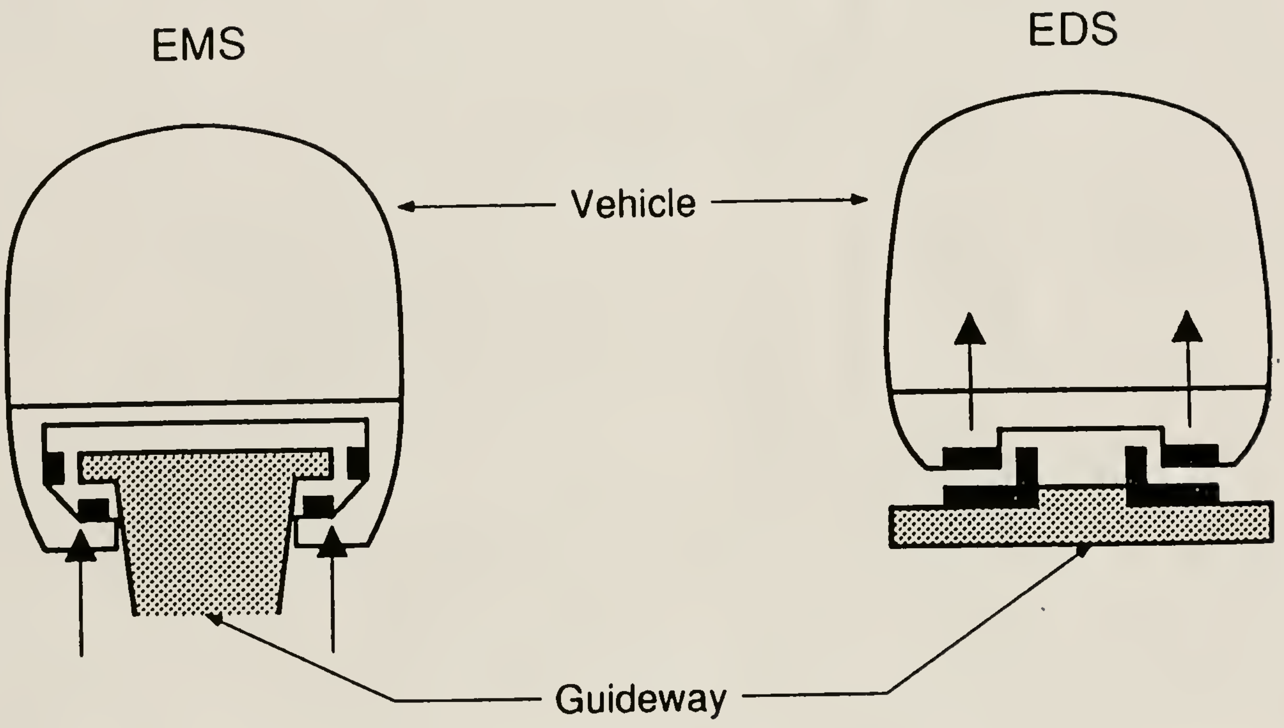


Figure 3-1: Attractive EMS and Repulsive EDS Levitation Modes
Source: Johnston et al., 1989.

Levitation of an EDS vehicle derives from the repulsive forces between superconducting magnets placed on the vehicle and induced electric currents known as eddy currents. Systems using EMS can levitate at rest. Systems relying on EDS require a certain speed before induced currents levitate the train. According to a study sponsored by USDOT (Uher, 1990), the EMS technology is several years ahead of the superconducting technology pursued by Japan and the United States.

The EMS systems operate with an air gap of less than a centimeter (0.4 in) because energy consumption increases with the square of the gap. The small air gap, however, limits maximum operational speeds to about 500 km/h (310 mph). The EDS systems tolerate an air gap ten times larger than EMS systems, allowing higher speeds and more flexibility in guideway design.

Another advantage of the EDS technology is its inherent stability. If the vehicle equilibrium position is disturbed by high wind or passenger movement, the intensity of the repulsive magnetic field varies and creates counteracting forces that tend to restore the vehicle to its initial position. On the other hand, the EMS technology is inherently unstable. Disturbances in the equilibrium position tend to generate forces that accentuate the unbalancing forces. Therefore, the air gap of EMS systems must be monitored continuously and continuous adjustments of the magnetic forces are required (Johnson et al., 1989). The power required to maintain the air gap is relatively small. Transrapid officials claim that it is not greater than the power consumed by the train's air-conditioning system (Heinrich and Kretzchmar, 1989).

The lightweight superconducting magnets of the EDS system are at present cooled by either liquid nitrogen or liquid helium. The discovery of materials that are superconducting at room temperature can further reduce the weight of EDS vehicles by eliminating the need to carry on-board refrigeration. Further, these superconducting materials will reduce energy transmission losses for both the EDS and EMS systems. Superconducting magnets produce an intense magnetic field that consumes less energy than EMS systems but requires shielding of passenger compartments. The present U-shape EDS guideway being tested in Japan is more complex and more expensive than Transrapid's EMS guideway. The U.S. research focuses on developing a simpler and less expensive guideway design by using material such as glass or carbon fiber reinforced plastic (Phelan and Triantafillou, 1992). This is theoretically feasible because EDS vehicles are lighter than EMS vehicles.

Further improvements in superconducting technology and guideway design are necessary to improve the financial feasibility of EDS systems. The EMS systems such as Transrapid or HSST have been approved for revenue operation. These EMS systems, however, may not be suitable or cost effective in regions prone to earthquakes or having low cohesive soils because of small tolerances in the guideway design that must be insured over the entire life cycle of the project.

## Tilt and Nontilt Trains

In corridors where it is not feasible to build new tracks and straightening the existing alignment is too expensive, operating a high-speed train may not be cost-effective nor comfortable due to constant acceleration/deceleration operations. If track's horizontal curvatures are the major constraint to higher-speed operation, a tilt train technology may be appropriate (TRB, 1991; USDOT, 1991a).

The main advantage of tilt trains is that they can travel up to 25% faster around curves than conventional trains and still provide the same passenger comfort level (as described in Chapter 2). Achieving the same level of speed improvement for nontilt trains may require curve excursions from existing right-of-way. This often means building expensive civil engineering structures and acquiring costly land.

On the other hand, tilt trains use self-steering trucks that align the wheels to the rails on curves thereby improving the distribution of dynamic loading on the rails. Self-steering trucks, however, limit the maximum speed achievable on tangent tracks to a maximum of 250 km/h (155 mph). The TGV and ICE employ a truck design with a stiff primary suspension to avoid unwanted oscillations at very high speeds (USDOT, 1991a). Another concern is that active tilt mechanisms add weight to each passenger car and increase the trainset's mechanical complexity (Hopkins, 1990). This is the main reason why some European manufacturers have abandoned tilt train research after having experimented with few prototypes. Generally, increased maintenance and reliability problems should be assessed individually for each tilt train technology.

Self-steering trucks are not applicable to maglev systems. However, tilt maglev technology may cause aerodynamic and vehicle stiffness problems, and also add weight and mechanical complexity. Maglev systems can more easily and very inexpensively increase the speed on curves by increasing the banking angle of the supporting system. While the draft U.S. regulations allow only a maximum track superelevation (i.e., banking angle) of 6 degrees for HSR systems, a track superelevation of up to 30 degrees is being considered for the U.S. maglev (USDOT, 1992). One degree of vehicle tilt has similar effect on passenger comfort as one degree of track superelevation.

# CHAPTER 4
# REVIEW OF HSGT LITERATURE

This chapter consists primarily of a review of government-sponsored studies. The reports reviewed include a study conducted by the Argonne National Laboratory and sponsored by the U.S. Department of Energy (1990), a study conducted at Carnegie Mellon Research Center (1991), several safety studies performed or commissioned by the USDOT and the Transportation Research Board, one special report published by the Transportation Research Board (1991), and a book written by the current president of the High Speed Rail/Maglev Association (1991). The literature related to train dynamics and simulation methods is examined in the following two chapters.

## Argonne National Laboratory Maglev Study

The Argonne National Laboratory study (Johnson et al., 1989) was the first major technical evaluation of maglev systems sponsored by a government agency since the federal government terminated funding for all HSGT research in 1975. The report's title is Maglev Vehicles and Superconductor Technology: Integration of High-Speed Ground Transportation into the Air Travel System. The study objectives were to identify the status of maglev research in the United States and abroad, identify potential markets, evaluate the impacts of high-temperature superconductors (HTSC) (i.e., room temperature superconductor), and assess the energy and economic benefits of maglev systems.

The study concludes that there is a potential domestic market for the maglev technology. The market, however, is not cost-effective from one downtown area to another because acquiring new right-of-way to provide access to urban areas can be very costly. The report indicates that the major maglev corridors should link airports and provide a substitute for flights of under 960 km (600 mi). This would significantly reduce air traffic congestion as well as noise and air pollution. A conceptual plan for connecting hub airports with maglev systems was developed and is shown in Figure 4-1.

It was estimated that maglev implementation can result in a substantial energy saving because flights of up to 960 km (600 mi) account for 45% of all energy consumed by commercial aircraft. A model was develop to estimate energy consumption by airlines and maglev systems. It was found that maglev vehicles consume as little as one-third of the energy used by aircraft over short distances. If 50% of short-haul flights could be replaced by maglev trips, this could result in a net saving of about 12% of the total fuel used by aircraft.

The report states that the discovery of room temperature superconductors can enhance the technical aspect of EDS maglev systems, reduce maglev vehicle weight by about 10%, and lower

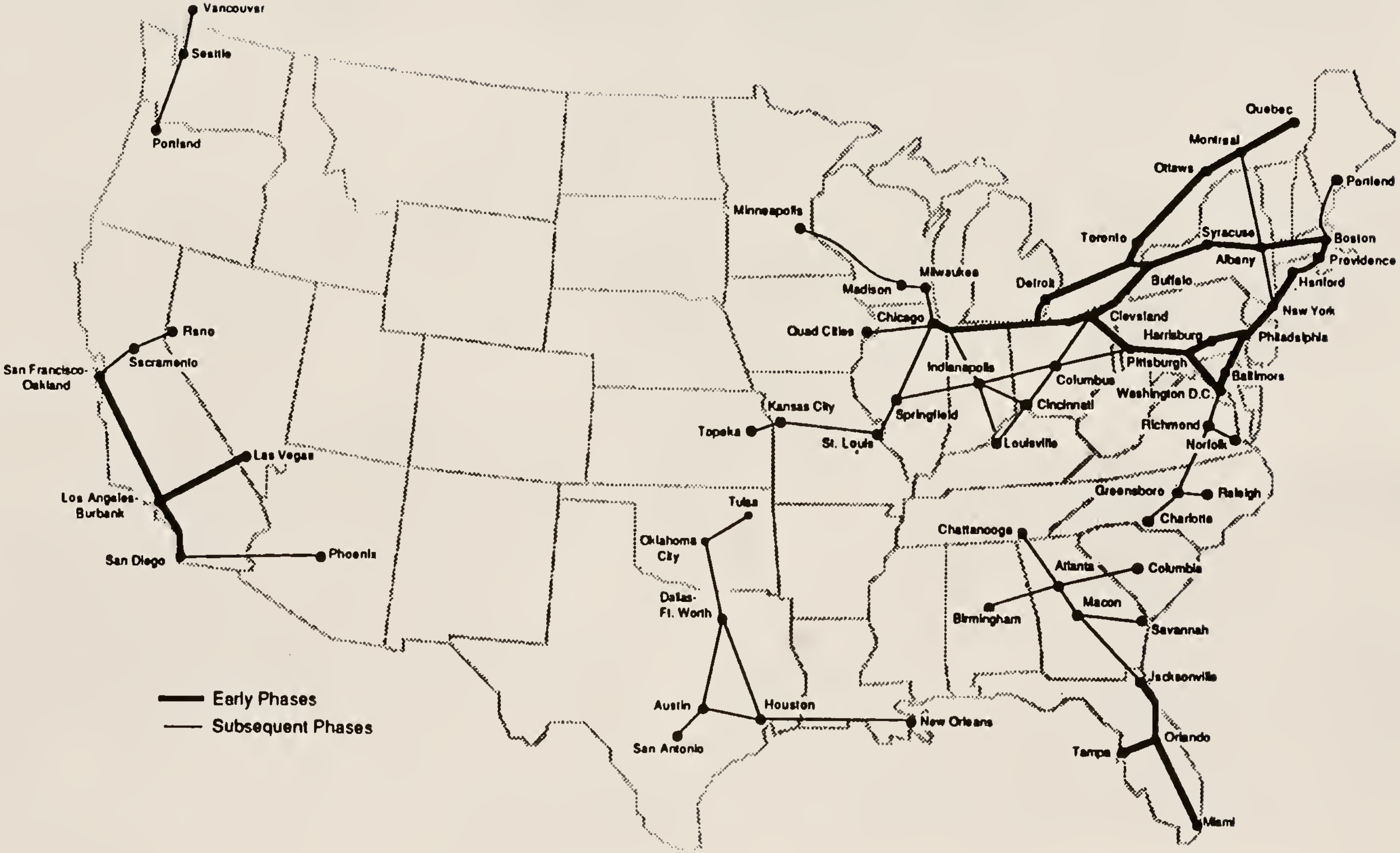


Figure 4-1: Conceptual Plan for Connecting Hub Airports with Maglev Systems
Source: Johnson et al., 1989.

energy and maintenance costs by an equal percentage.

In addition, it was found that the capital costs of maglev systems are difficult to estimate. The report contains a reference to cost estimates prepared for the Las Vegas to southern California route. However, there are today indications that these estimates are too optimistic. The Argonne report also indicates that dedicated HSR systems are expected to cost almost as much as maglev systems, but will have higher operating costs. Neither of these claims can be established, and recent cost estimates suggest otherwise (Buckeye, 1992).

The Argonne National Laboratory is currently conducting several maglev studies funded primarily by the National Maglev Initiative Research Program. These studies deal with research areas such as high-temperature superconductors maglev system, vehicle/guideway interaction, flexible guideway, preliminary design for maglev facility, maglev system design considerations, and maglev potential role in short-haul airline operations.

### Carnegie Mellon University Study

The study conducted by the Carnegie Mellon University (CMU) (Uher, 1990) was funded by a grant from the USDOT. The CMU established an HSGT center in January, 1987. The center initially evaluated a maglev technology developed by Boeing under contract to the USDOT. Boeing discontinued the maglev research after the USDOT stopped funding the project.

The CMU review indicated that the Boeing technology was not suitable for a maglev regional system. Instead, the German Transrapid technology was viewed as the most advanced maglev system and the most appropriate for Pittsburgh.

The CMU research team predicted a significant HSGT market, estimated at over $200 billion. This forecast was based on two elements: highway congestion and air traffic congestion. Highway congestion was estimated to increase vehicle delay from 3 billion hours in 1985 to 12 billion hours in 2005, and the attendant costs could increase from $12 billion to $46 billion as shown in Table 4-1. The cost of delay due to air traffic congestion was estimated to increase from $5 billion in 1986 to $13 billion in 2005 as shown in Table 4-2. It is important to note that these estimates were made at a time of rising demand. Recent increases in travel demand are below these projected estimates.

The main feature of the CMU report is the proposal of a conceptual 1800 km (1130 mi) regional maglev system for Pittsburgh. The estimated capital cost was $29.2 billion in 1990 dollars ($26 million per mile). The annual operating costs were estimated at $295 million (1990 dollars). It was projected that the regional system could potentially generate an economic activity of $96 billion during construction and $885 million during operation.

The first phase of the proposed project would consist of a demonstration segment linking Pittsburgh airport to the

Table 4-1: Cost of Vehicle Congestion to the Highway User

| VEHICLE CONGESTION | 1985 (billion) | 2005 (billion) | Increase (%) |
|---|---|---|---|
| Urban Freeway Congestion | 1.6 | 8.1 | 406% |
| Signalized Arterial Congestion (hours) | 1.1 | 3.8 | 245% |
| Total Congestion (hours) | 2.7 | 11.9 | 341% |
| Person-Hours (a) | 3.2 | 14.3 | 347% |
| Gallons Fuel (b) | 0.8 | 3.6 | 275% |
| Congestion Cost (c) | $12.2 | $46.5 | 281% |

(a) 1.2 persons per vehicle
(b) 0.3 gallons of fuel per vehicle-hour
(c) $3.0/person-hour + $1.0/gal

Source: Uher, 1990.

Table 4-2: Cost of Air Congestion

| DEMAND | 1986 | 2005 |
|---|---|---|
| Enplanements | 414 millions | 887 millions |
| Passenger Miles | 359 billions | 935 billions |
| Air Operations | 29 millions | 46 millions |
| Airports with Chronic Delay (delay greater than 8 min/operation) | 11 airports | 41 airports |
| Cost of Delay | $5.0 billion | $13.3 billion |

Source: Uher, 1990; USDOT, 1987.

downtown area at a cost between $300 million and $650 million. It was expected that the demonstration project will recover its operating cost but not its capital cost. Plans were proposed to develop economic activity nodes at maglev stations. In addition, a manufacturing license would be negotiated with Transrapid, and components of the maglev system would be supplied by Pittsburgh-based companies. This is consistent with one of the main objectives of the proposed regional maglev system which consists of establishing a maglev industrial base in Pittsburgh.

### USDOT Safety Reports

The growing interest in HSR and maglev systems generated a need to reexamine existing U.S. safety requirements as well as the suitability of European and Japanese technologies to the U.S. market. These advanced HSGT systems employ differing equipment and operating procedures than conventional rails. This required an examination of their safety in U.S. operation and a rethinking of the federal approach to safety design and regulations in order to avoid impending new technology as a result of past regulations designed for conventional rails.

A series of safety reports were produced by the Federal Railroad Administration (FRA), a division of the USDOT, which is in charge of assuring the safety of rail systems in the United States as stipulated in the Federal Railroad Safety Act of 1988. Most of the safety studies were performed by the USDOT's John A. Volpe National Transportation Systems Center.

Four HSGT safety reports were published in 1991 under the series Moving America: New Directions, New Opportunities. The first report, titled Safety relevant Observations on the X-2000 Tilting Train (USDOT, 1991a), examined safety issues related to the Swedish ABB X-2000 tilt train. The second report, titled Safety of High-Speed Magnetic Levitation Transportation Systems: Preliminary Safety Review of the Transrapid System (USDOT, 1991b), addressed the safety of the German Transrapid maglev system. The third report, titled Safety Relevant Observations on the TGV High-Speed Train (USDOT, 1991c), reviewed the safety of the French TGV high-speed train system. The fourth report, titled Safety Relevant Observations on the ICE High-Speed Train (USDOT, 1991d), reviewed the safety of the German ICE high-speed train system.

These FRA safety reports are of a preliminary nature. They were initiated in response to the various corridor feasibility studies and franchise applications to build and operate an HSGT system in the United States. The X-2000 train was proposed for application in the Northeast Corridor between New York and Washington, D.C.; and in Florida to provide a rail service between Miami, Orlando and Tampa. The Transrapid maglev system was proposed for implementation in Orlando, Pittsburgh, and between Anaheim and Las Vegas. The TGV system was proposed for implementation in Florida, Texas, California and other states. The ICE system was also proposed for implementation in Texas, however the ICE proposal was not selected by Texas authorities. The FRA is currently conducting a more detailed review of these technologies, examining all the requirements needed for their approval to operate in revenue service in the United States.

### Safety Issues Related to the X-2000 Tilt Train

The safety report related to the X-2000 tilt train (USDOT, 1991a) presents an overall description of the system; a preliminary evaluation of the tilt technology; and a review of the safety features related to the tilting mechanism, steerable trucks, braking system, and automatic train control. Compliance with existing FRA regulations were also examined. This includes compliance with the standards for noise emission, track safety, marking devices, glazing (windshields and window glass), locomotive safety, control system, and fire safety.

This preliminary evaluation indicates that the train operator's console exceeds U.S. industry practices in terms of ergonomics and cabin noise standards. The noise emitted by the X-2000 measured at 25 meters (82 ft) at 200 km/h (125 mph) was no greater than a conventional train at 130 km/h (80 mph). The brake system was found to operate smoothly and effectively. The stopping distances for emergency applications were well within U.S. accepted standards. Some modification of the train interior were needed to meet flammability standards and disabled access. These modifications, however, can be performed without major difficulty. There remained certain issues for which not enough data was available to complete the evaluation. The X-2000 manufacturer, however, indicated their intention to meet FRA safety requirements for any permanent U.S. application.

### Safety Issues Related to the Transrapid Maglev Train

The safety reports related to the Transrapid maglev system (USDOT, 1991b; FRA, 1992) present a description of the Transrapid-07 vehicle and infrastructure, a comparison of FRA and foreign safety standards, and an assessment of potential maglev safety issues. The maglev technology poses two safety concerns: first, the technology differs from the steel rail system and requires new regulations; second, maglev systems have only been operational on test tracks, and therefore inadequate information is available to assess their performance in revenue service throughout the system's life cycle.

The FRA developed a maglev safety analysis method known as the System Safety Concept. It consists of applying managerial and technical skills to systematically identify potential hazards early in the system design, and to recommend design modifications necessary to ensure safety before the system is actually built. The hazard resolution process was achieved by identifying hazards, assessing their severity and probability, and developing corrective measures.

Potential safety issues were identified from operating experiences, expert opinions, and a generic hazard checklist. Expert opinions were used to assess the severity and probability of each identified hazard. A risk assessment matrix was developed to assist in the decision making process to determine whether individual hazards can be accepted, or they should be eliminated or controlled. Table 4-3 presents the estimated probability of identified hazards, and Table 4-4 shows the risk matrix developed for the Transrapid system.

The FRA initiated a review process of maglev safety standards and guidelines developed in Germany and other countries to assist in adapting U.S. railroad regulations to the maglev system. The structural design standards used for aircraft bodies were also reviewed for possible relevancy to maglev vehicle design. It was determined that modification of existing FRA regulations may be required to accommodate maglev systems in areas related to emergency braking, window glazing, signal and train control, power supply, personnel qualification and operating rules.

More detailed information was needed by FRA to evaluate fully the ability of the Transrapid system to perform safely in U.S. applications. A one-year test program of the Florida Maglev Demonstration Project was viewed as vital for obtaining adequate data on safety issues such as the dynamic interaction between vehicles and guideway, operation in very high winds, soil erosion, guideway oxidation, and extreme thermal

Table 4-3: Probability Estimates of Undesired Events in Maglev Operation

| EVENT DESCRIPTION | OPERATIONAL PHASES INVOLVING PASSENGERS | | | |
|---|---|---|---|---|
| | Passenger Station Transfer | Leaving/ Arriving Station | Accessible Areas of Guideway | Inaccessible Areas of Guideway |
| Fire/Explosion in Vehicle | D | D | D | D |
| Fire in Other Critical Element | C | C | C | C |
| Vehicle Collision with Object | C | C | C | C |
| Vehicle to Vehicle Collision | D | D | D | D |
| Vehicle Leaves Guideway | E | E | E | E |
| Sudden Stop | N/A | D | D | D |
| Does Not Slow/Stop at Station | N/A | D | N/A | N/A |
| Stranded on Guideway | N/A | D | C | C |
| Inability to Rescue Occupants | D | D | D | C |
| Passenger Illness/Injury | C | C | C | C |

| LEGEND: | | |
|---|---|---|
| | A | Frequent |
| | B | Probable |
| | C | Occasional |
| | D | Remote |
| | E | Improbable |
| | N/A | Not applicable |

Source: USDOT, 1991b

Table 4-4: Maglev Risk Assessment Estimates

| EVENT DESCRIPTION | OPERATIONAL PHASES INVOLVING PASSENGERS | | | |
|---|---|---|---|---|
| | Passenger Station Transfer | Leaving/ Arriving Station | Accessible Areas of Guideway | Inaccessible Areas of Guideway |
| Fire/Explosion in Vehicle | IID | ID | ID | ID |
| Fire in Other Critical Element | IIIC | IIIC | IIC | IC |
| Vehicle Collision with Object | IIC | IIC | IC | IC |
| Vehicle to Vehicle Collision | IID | IID | ID | ID |
| Vehicle Leaves Guideway | IIE | IIE | IE | IE |
| Sudden Stop | N/A | IIIC | IIC | IC |
| Does Not Slow/Stop at Station | N/A | IID | N/A | N/A |
| Stranded on Guideway | N/A | IID | IIC | IC |
| Inability to Rescue Occupants | IIID | IID | IID | ID |
| Passenger Illness/Injury | IIIC | IIC | IIC | IC |

| LEGEND: | | | | |
|---|---|---|---|---|
| | I | Catastrophic | A | Frequent |
| | II | Critical | B | Probable |
| | III | Marginal | C | Occasional |
| | IV | Negligible | D | Remote |
| | | | E | Improbable |
| | | | N/A | Not applicable |

NOTE: IA, IB, IC, IA, IIB, IIIA = Unacceptable;
ID, IIC, IID, IIIB, IIIC = Unacceptable (management decision required);
IE, IIE, IIID, IIIE, IVA, IVB = Acceptable with review by management;
IVC, IVD, IVE = Acceptable without review

Source: USDOT, 1991b

conditions. This information was considered critical towards approving Transrapid for revenue operation in the United States.

## Safety Issues Related to the TGV Train

On May 28, 1991, the Texas TGV Consortium, headed by the Morrison Knudsen Corporation, was awarded a 50-year franchise to design, build, and operate a high-speed rail system in Texas between the cities of Houston, Austin, Dallas and San Antonio (referred to as the Texas Triangle). The French TGV train is the technology selected by the franchisee for operation in Texas

The FRA undertook this safety study to examine which of existing regulations may have to be adapted to cover the unique characteristics of the TGV, and also to identify the aspects of TGV's design, construction and operation that need to be changed to meet specific U.S. customer applications.

The report indicates that although the review is preliminary, the TGV system seems to comply (or comply with minor modifications) with FRA standards for track safety, control of locomotive, braking system, air brake equipment, electrical systems (except the emergency pantograph pole), cab equipment, signal system, train control system, automatic block signal system, interlocking, traffic control systems and automatic train stop system. The Texas TGV trainset will provide wheelchair accommodation and a handicapped washroom in compliance with the Americans with Disabilities Act of 1990.

Further measurements were needed to confirm compliance with noise emission requirements, fire protection guidelines, and the safety windshield and glazing standards. The Windshield and glazing safety standards at high speed are not addressed in FRA's existing regulations. This is important because the kinetic energy of a collision with an object is greatly influenced by speed.

The report concludes that the proposed Texas TGV system presents unique features compared to the customary intercity passenger train designs found in the United States. The FRA's existing regulations were not designed for railroad operations in excess of 176 km/h (110 mph); and do not permit rail passenger operations at higher speeds (Amtrak operates at speeds up to 200 km/h (125 mph) on the Northeast Corridor under a waiver). The Texas TGV rolling stock is capable of 320 km/h (200 mph). Furthermore, the TGV operates as a fixed trainset with an articulated passenger section consisting of several cars. Therefore, the on-board microprocessor network, the speed control system, the signal system, and the braking system are all designed based on the operation of equivalent trainsets; and should be taking into consideration in formulating new safety regulations. The FRA needs also to develop standard for fault-tolerant systems, and for the reliability of computer hardware.

## TRB Safety Reports

The Transportation Research Board (TRB) published two circulars dealing with the safety of HSR and maglev systems. The most recent Circular #387 (TRB, 1992) consists only of research problem statements. The problem statements were generated at a special workshop conducted at the request of FRA. The workshop objective was to assist FRA develop appropriate safety regulations for HSR and maglev systems. Approximately 70 research problem statements were identified. These problem statements are being addressed within the National Maglev Initiative Research Program. The safety issues were subdivided into the following four topics:

- Maglev guideway and vehicles.
- HSR guideway and vehicles.
- System design criteria and operation of maglev and HSR.
- Issues related to signal, control and power supply.

The TRB Circular #351 (TRB, 1989), titled Safety Factors Related to High-Speed Rail Passenger Systems, addresses only the safety issues of HSR systems. The purpose of this effort was to review regulations and practices in several European nations, and to obtain information on the European experience in operating HSR systems in revenue service.

The report describes the basic differences in railroad safety regulations between the United States and Europe. The European approach to railroad safety is based on "designing safety into the system" by assessing safety requirements for each corridor, whereas the U.S. approach consists of insuring safety through regulations. In most European countries, the national railroad company itself has the primary responsibility for safety, while the government has responsibility to oversee and to approve or disapprove the railroad's actions. Although European governments have regulatory power, they generally do not exercise it through detailed regulations as is the case in the United States. Another important distinction is that local governments in most European countries have no jurisdiction over the operation of the national railroad network except through specific agreements for local service.

The report also presented a description of European safety considerations as related to HSR systems in areas of rolling stock, infrastructure, signalization, electrification, and communication systems. There was, however, no comparisons made with corresponding FRA regulations.

### TRB Special Report 233

The TRB Special Report 233 (TRB, 1991), titled In Pursuit of Speed: New Options for Intercity Passenger Transport, provides an impartial evaluation of HSGT systems and their potential feasibility in the U.S. market. This 179-page special report was prepared at the request of the USDOT. Several consultants assisted the TRB committee members in the preparation of this document. Among the consulting companies that participated in this effort are the Canadian Institute for Guided Ground Transport (CIGGT), Parsons Brinckerhoff Quade and Douglas (PBQD), SYDEC, and Analytic Services. The report includes a review of costs, ridership, financial feasibility, and public support of HSGT systems. Most of the information was based on previous feasibility studies and the various proposals for HSGT systems. The cost section of the report was prepared with the assistance of John Harrison of PBQD. This section and other HSGT studies performed by PBQD were extensively used in this dissertation's HSGT cost analysis because they constitute the only completed theoretical (i.e., not related to any specific corridor) maglev cost studies commissioned and funded by the USDOT.

The report concludes that the high cost of HSGT systems and the uncertainty in forecasted demand are the main reasons that neither public initiative nor private enterprise has produced an operating system in the United States. The report also states that it is unlikely that HSGT systems will pay for themselves under reasonable ridership estimates and farebox revenues. Therefore, public support will likely be required in most cases. According to this report, the justification for public support can be based on a host of secondary benefits (often referred to as externalities) to nonusers or the general public. These benefits include congestion relief, environmental advantages, economic impacts, and greater control of land use development patterns. The report indicates, however, that further studies are needed to evaluate these secondary benefits and devise methods to estimate them on a site specific basis.

## Supertrains Book

The book Supertrains, Solutions to America's Transportation Gridlock (Vranich, 1991) is written by Joseph Vranich, the current president of the High Speed Rail/Maglev Association (HSR/MA). The book was not intended to be a scientific study. Mr. Vranich is a strong advocate of HSGT systems, and his involvement with HSR/MA makes him quite knowledgeable in this area. He was called on numerous occasions to testify in congress hearings on HSGT-related topics. His most recent testimony was on August 6, 1992, before the U.S. Senate's Committee on Commerce, Science, and Transportation.

The Supertrain book presents a summary of the advantages of HSR and maglev technologies and a description of the systems operational in Europe and Japan. Although the book contains no new technical information, it provides a unique insight into the working of Congress and the political context of transportation funding decisions. Government actions can have a major impact on the implementation of HSGT systems in the United States. As mentioned is the previous section, very few HSGT corridor studies indicated that their proposed HSR or maglev system will be expected to recover its capital cost. Therefore, some sort of government support will be required in most cases.

Although legislative actions related to tax-exempt bonds and highway right-of-way use are important for HSGT systems, the main legislative maglev issues are related to the level of funding and whether the appropriated funds should be used to develop a domestic maglev technology or to implement "americanized" foreign maglev systems. The author believes there are justifications for the federal government to subsidize the construction of HSGT systems. The HSGT systems are safer, more energy efficient and less polluting than other modes. The author enumerates all the direct and indirect subsidies (he referred to them as hidden subsidies) to the highway system and airline companies. Furthermore, he claims that airplane manufacturing industries have greatly benefited from military research programs by adapting the findings to civilian use.

The legislators who favor investing in the development of a domestic maglev technology claim that the Japanese MLU maglev is too expensive and not yet operationally ready, and the German Transrapid maglev uses conventional electromagnets and must levitate with small air gaps which limits speed and increases guideway cost. They propose developing from scratch a new generation of superconducting maglev technology specifically suited for the U.S. market.

The legislators who favor americanizing a foreign technology are more interested in a quick implementation of the already proposed maglev systems, such as the systems proposed for Orlando and Pittsburgh. Some of them claim that investing in developing a U.S. maglev system is mainly designed to assist aerospace and military industries overcome military cutbacks. They are skeptical that U.S. industries can in a short time and cost-effectively develop a substantially better maglev technology than what is already available. They don't foresee significant technological breakthroughs and they believe it will be too expensive to match the billions of dollars invested by the Germans and Japanese and the 15-year experience gained by their researchers. They also claim that americanizing (obtaining a manufacturing license) a foreign maglev technology, such as the Transrapid, can lead to a domestic manufacturing maglev industry with almost equal benefits to the U.S. economy as developing a new system (this reasoning is also held by the researchers of the Argonne National Laboratory who proposed the Pittsburgh maglev regional network using Transrapid technology). The author remarks that the world manufacturing process is becoming more integrated. Even Boeing airplanes contain foreign-manufactured parts. He therefore advises against delaying proposed systems until a U.S. technology is ready for implementation.

Finally, the author states that maglev vehicles account for a small percentage of the total cost of a maglev system. The largest cost components are for guideway, earthwork, and civil engineering structures. The spin-off from these investments alone can generate important ramifications for the local as well as national economy, regardless which maglev technology is used.

# CHAPTER 5
# TRAIN DYNAMICS

This chapter provides a description of resistive forces acting on a train, the engine power needed to accelerate a train on a level terrain and on grades, and the allowable speed on curves. Most units in this chapter are expressed in SI units only.

For a train to move forward and accelerate, its motors must produce a tractive force superior to the sum of all resistive forces. The acceleration rate is proportional to the resultant force and limited by the adhesion coefficient between rail and wheel.

The total resistance is the sum of all resistive forces acting on a train at a given time or place. Traditionally, it was measured in pounds per ton of train. The FRA has recently adopted the metric system, and today total resistance is measured in SI units (Systeme International) and expressed in KN (Kilo Newton). The SI unit "tonne" equals 1000 kg and about 1.103 U.S. short tons.

The resistive forces acting on an HSR train are different from the forces acting on a maglev train because maglev systems operate without physical contact. At high speed, however, air resistance becomes the dominant resistive force for both HSR and maglev systems.

## Resistive Forces Acting on HSR Trains

According to Hay (1982), Petersen (1985) and Lacote (1986) the main resistive forces acting on a steel-wheel train traveling on a level terrain can be classified as follows:

1. Resistances varying with the axle loading such as rolling resistance and track resistance.
2. Resistances varying with the speed such as flange friction, oscillation, swaying and concussion.
3. Resistance varying with the square of the speed which consists of air resistance.
4. Resistances due to temperature, curves and wind.

### Rolling Resistance

The rolling resistance results from friction between the wheel tread and the head of the rail. Train’s rolling resistance is very low compared to cars, trucks and ships because the contact area is extremely small and the amount of wheel surface flattening is minute due to steel’s stiffness. It takes a relatively small force to move a train forward on a level terrain. The total rolling resistance depends on the train’s weight, types of metals in wheel and rail, and contact surface condition (e.g., wet, dry, oily, rusted or frosty).

### Track Resistance

The track resistance is caused by track depression at contact points with wheels. The track bends causing the wheel to run "uphill."  The track resistance increases with higher axial loading and decreases with higher track stiffness.

### Flange Resistance

The flange resistance is caused by the random contact of the wheel's flange with the head of the rail. This random contact is mainly due to irregularities in track alignment. The flange resistance causes a retarding force as well as lateral vibrations. Lateral or vertical movements of the wheels generate swaying, concussion and oscillation of the trainset. The flange resistance is intensified by poor track condition and increases with speed. It also varies inversely with the distance between the axles (i.e., wheel base). To minimize flange resistance at high speed, the track must be designed to high standards and rail alignment must be checked regularly.

### Air Resistance

Experimental tests (FRA, 1974) have indicated that air resistance varies approximately with the square of the speed. It also varies linearly with the train's cross-sectional area. Air resistance depends on streamlining for speeds above 90 km/h (60 mph). Streamlining assumes great importance at speeds above 200 km/h (125 mph). Reducing air drag requires an aerodynamic shape of the leading unit (power car), a smooth exterior surface with minimum irregularities, a small cross-section pantograph, and an articulated connection between passenger cars to form a continuous body.

Early wind tunnel tests conducted in the 1930s at the Massachusetts Institute of Technology resulted in the following Totten Formula (Totten, 1937) for streamlined trains:

$$R_a = [0.001735\ P_c\ (L_c/100)^{0.88} + K_c]\ V_2$$

Where: $R_a$ = air resistance (lb)

$P_c$ = perimeter of train (ft) (default=35 ft)

$L_c$ = length of train (ft)

$K_c$ = streamlined design factor

$V$ = speed (mph).

Air resistance studies for HSR systems do not use such simplified formulas nor rely on design assumptions. Actual scale models are extensively tested in wind tunnels to develop the optimal streamlining possible, years before a prototype is built. Wind tunnel testing continues uninterrupted on actual trainsets to reduce the drag coefficients of newer models. For instance, improved streamlining reduced the air resistance coefficient of TGV-A as compared to TGV-SE, and that of Transrapid 07 as compared to Transrapid 06.

### Resistances Due to Temperature, Curves and Wind

The ambient temperature is important for starting resistance because it affects the viscosity of lubricants. The curve resistance is caused by the friction between the flanges and tread of the wheels and the rails (principally the outside rail) as the train travels around a curve. The curve resistance, however, is often ignored in train simulations because it is a very small force compared to air resistance, and is present only on a small percentage of the route.

Winds cause an additional resistive force with an amplitude that depends on the wind direction. Wind perpendicular to track alignment can cause oscillation. Lateral forces are resisted by dampening mechanisms and by an articulated design of passenger cars (La Vie Du Rail, 1990).

## Modeling HSR Total Resistance

Several formulas were developed in the past to estimate the total train resistance. The Davis formula was developed based on plots of data of previous studies conducted by the railroad companies of Pennsylvania, Burlington and Illinois. The Davis formula to estimate the total resistance per unit weight is the following (Hay, 1982):

$$R_u = 1.3 + \frac{29}{w} + bV + \frac{CAV^2}{wn}$$

Where: $R_u$ = unit resistance (lb/ton)
w = weight per axle (tons)
b = an experimental coefficient based on flange friction, sway and concussion
A = train's cross-sectional area ($ft^2$)
C = drag coefficient derived from experiments
n = number of axles in the train
V = speed (mph).

The Davis formula was modified in 1970 by Committee 16 of the American Railway Engineering Association (AREA). The intent was to adjust it for higher operating speeds and to take into account improved track design and modern railroad practices. The modified Davis equation is the following:

$$R_u = 0.6 + \frac{20}{w} + 0.01\ V + \frac{KV^2}{wn}$$

Where K = air resistance coefficients derived experimentally for various types of trains

$R_u$, w, n and V are the same as in the original Davis equation.

The default K factors developed for this equation were subsequently found to overestimate air resistance, and new adjusted values were later developed.

These Davis and Modified Davis formulae provide approximate estimations of resistive forces for the various passenger and freight trains in operation in the United States. Prior to these equations, an average value of 27 N/tonne (6 lb/ton) was frequently used for train resistance, and a value of 3.6 N/tonne (0.8 lb/ton) for curve resistance. These equations are not, however, valid for HSR systems because they do not accurately simulate air resistance at high speeds. Their usefulness is primarily to illustrate the relative weight of the parameters that contribute to the train's total resistance.

The total resistances of the HSR systems examined in this study were derived by measuring the resistive forces on actual trainsets. The expression that describes the train resistance ($F_t$) of a system have the general form of: $F_t = A + BV + CV^2$, where V represents speed and A, B and C are coefficients.

Selected total resistance expressions of TGV trainsets based on the assumption of level terrain and a wind force of 8 km/h are the following (see also Appendix F):

TGV-PSE (1P+8T+1P): $F_t = 254 + 3.34\ V + 0.0572\ V^2$

TGV-2N (1P+8T+1P): $F_t = 261 + 3.63\ V + 0.0670\ V^2$

TGV-A (1P+10T+1P): $F_t = 295 + 3.92\ V + 0.0624\ V^2$

TGV-TMST (1P+18T+1P): $F_t = 482 + 6.53\ V + 0.1050\ V^2$

Where: $F_t$ = Total resistance in daN (1 daN=0.01 KN)

V = Speed (km/h)

## Resistive Forces Acting on Maglev Trains

The contactless operation of an EMS maglev train eliminates all the resistive forces generated by friction such as rolling resistance, track resistance, flange friction and curve resistance (Merklinghaus, 1989). A small rolling resistance remains for EDS maglev systems at low speeds before superconducting forces levitate the train. The total resistance of an EMS maglev system (and EDS maglev after levitation) has three components (Ciessow et al., 1989):

1. Resistance due to linear generators.
2. Resistance of suspension and guidance magnets.
3. Aerodynamic resistance.

### Resistance of Linear Generators

Linear generators provide the power needed on board the vehicle for exciting the magnets and for other uses such as the air-conditioning system and auxiliaries. The propulsion power is transmitted without contact via the magnetic motor field. These generators have three phase windings (electric coils) that are located near the suspension magnets. Flux variations due to train's movement induce voltages in the windings that recharge the on-board batteries. The intensity of the induced voltage is function of speed. The resistive force attributed to the linear generators decreases with speed.

### Resistance of Suspension and Guidance Magnets

The suspension and guidance magnets result in eddy-current type resistive force (caused by a moving object in a magnetic field) that should be overcome by the tractive power. This resistance remains relatively constant over the speed range of the train as shown in Figure 5-1, because it depends primarily on the train's weight.

### Maglev Aerodynamic Resistance

The aerodynamic resistance is function of speed and streamlining. It becomes by far the largest component at very high speeds. For instance, a doubling of the power is needed to raise Transrapid speed from 300 km/h to 400 km/h (188 mph to 250 mph). Techniques and materials used in the aerospace industry are generally adopted for designing maglev's car body to insure structural stiffness, low aerodynamic drag coefficient, and lightweight components (Gaede and Kunz, 1989). The aerodynamic resistance and the total resistance for the Transrapid train are also shown in Figure 5-1.

## HSR and Maglev Tractive Power

The tractive power depends on the engine's rated power and its efficiency rate. The engine's power is measured in SI units in kilowatts (KW) or in US units in horsepower (HP). The older HSR trains such as the TGV-SE are powered by direct current (DC) motors. The DC motor has a high starting power and can use the power from a DC catenary almost directly. However, DC motors have limited maximum speed due to commutation, and current losses are less with alternating currents (AC). The newer generation of HSR systems rely on self-commutated AC motors. The three-phase AC motors are lighter and more powerful than DC motors. They are also easier to maintain because there is no commutators (Cossie et al., 1986). The popularity of AC motors is largely due to the advance in the thyristor control technology. The thyristor is an electronic component that passes electric current in only one direction, provided a suitable polarity is applied to its control electrode (La Vie du Rail, 1990). Without this polarization, the current cannot flow through the thyristor. Thus the thyristor acts both as a rectifier of the AC current (allowing current to pass in one direction only) and as a switch (by changing polarity).

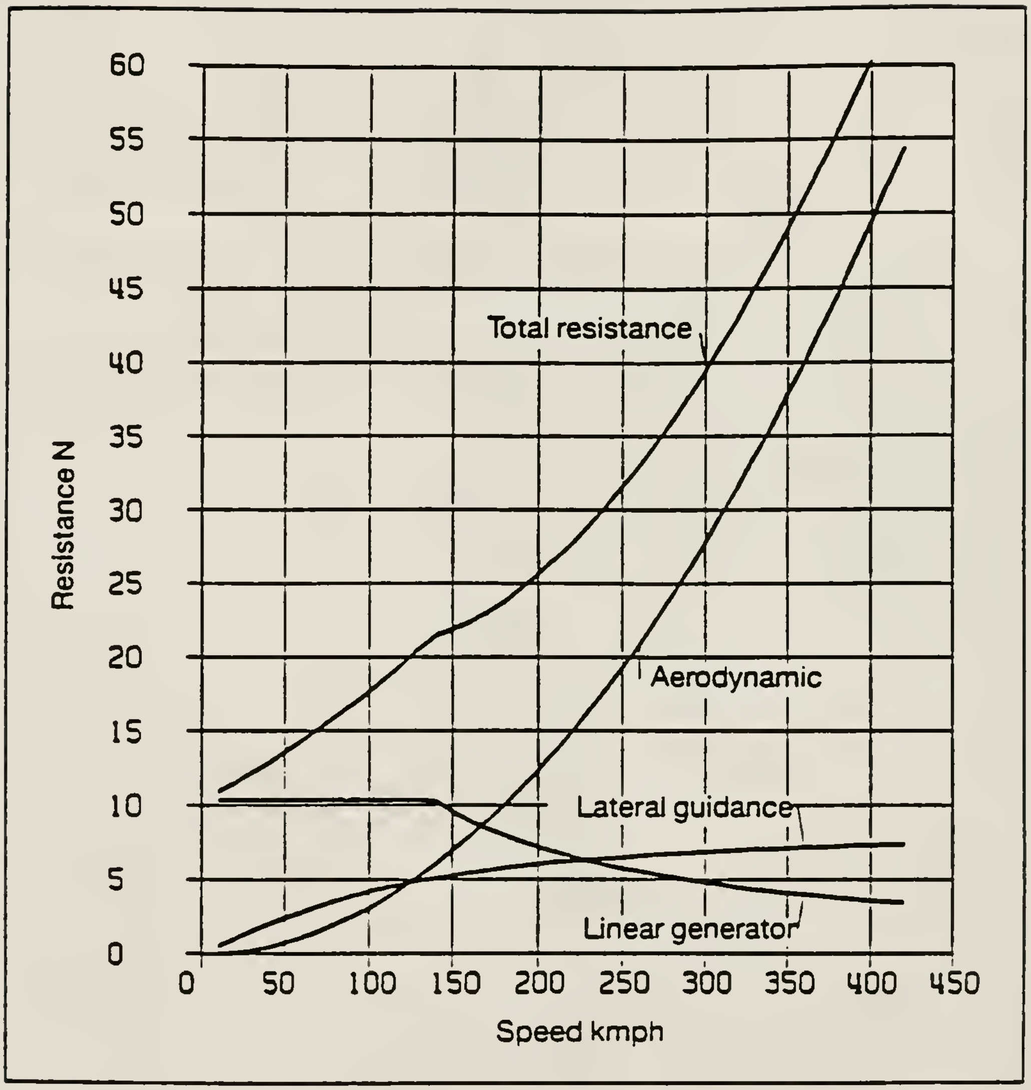


Figure 5-1: Resistive Forces Acting on Transrapid
Source: Merklinghaus, 1989.

The tractive power increases with the current and voltage. Theoretically it can be unlimited. In practice it is limited by engine heating and wheel/rail adhesion limits. The tractive power of HSR systems is usually expressed in three different values:

1. Continuous rating power.
2. One-hour rating power.
3. Starting tractive effort.

The continuous rating power is the maximum tractive power which the power car can exert continuously without harm to the motors. The one-hour rating power is the safe power that can be handled safely for an hour. Because the heating does not occur at once, the motors can be overloaded for a limited period of time. The starting rating power is the maximum power that can be produced for a short period of time, generally used for starting the train. The starting power is typically measured in Newtons (N) or pounds (lb) and the continuous and one-hour ratings in Kilowatts (KW) or horsepower (HP). The tractive power ratings for the TGV-SE, TGV-A, ICE and X-2000 power cars and other technical data are given in Table 5-1. The total tractive power of the Japanese bullet train depends on the number of cars in the train because each car is designed to generate its own tractive force.

## Acceleration on Level Terrain

The instantaneous acceleration of a trainset is governed by Newton's second law of motion, which states that acceleration of an object is equal to the resultant force acting on the object divided by the object's mass. The net force generated by the motors and available at the wheels is referred to as the "net" tractive effort or drawbar pull. This force must be greater than all resistive forces in order for the train to accelerate. If the tractive power is less than all resistive forces, the train decelerates. The train travels at a constant speed when traction equals all resistive forces.

The tractive effort should not exceed safe adhesion levels between wheel and rail, as determined by measured adhesion coefficients. Otherwise, wheel slipping occurs increasing wear and maintenance cost. Wheel slipping is prevented by anti-slip protection systems and by using continuous welded rail (USDOT, 1991c).

The net tractive effort decreases with speed as shown in Figure 5-2. The reason is that as speed increases, a portion of the tractive power is used to maintain the speed, and only the residual power is available for acceleration. In technical terms, a voltage drop occurs in the motor caused by a counter electromotive force (CEMF) that increases with speed. In a synchronous motor, such as the motors utilized in the new generation of TGV trains, the CEMF is used to "naturally" commutate the inverter thyristor, allowing higher RPM (rotations per minute) than asynchronous motors used in HSR systems such as the ICE and the X-2000.

Table 5-1: High-Speed Rail and Maglev Comparison Matrix

| TECHNOLOGY | TGV-A | ICE | ABB X-2000 | Transrapid 07 |
|---|---|---|---|---|
| TRAINSET | | | | |
| Consist Makeup | 1P-10T-1P | 1P-14T-1P | 1P-5T | 1P-4T-1P |
| Length (m) | 237.6 | 410.7 | 140 | 153.1 |
| Total Weight (SI Tons) | 484 | 950 | 338 | 342 |
| Capacity (pass) | 485 | 759 | 255 | 608 |
| Top Speed (km/h) | 300/320 | 280/300 | 200/240 | 350-500 |
| Max. Gradient (%) | 5 | 4 | 3 | 10 |
| Max. Superelevation (Deg) | 7.1 | 7.1 | 6 + 6.5 tilt | 12 |
| POWER CAR | | | | |
| Length (m) | 22.1 | 20.6 | 17.0 | 27.0 |
| Width (m) | 2.92 | 3.07 | 3.08 | 3.70 |
| Height (m) | 4.01 | 3.84 | 3.8 | 4.06 |
| Weight (metric tons) | 67.8 | 78.2 | 73 | 45.0 |
| Traction Motor Type | AC Synch. | AC Async. | AC Async. | AC Sync. |
| TRACTIVE EFFORT | | | | |
| Starting Effort (KN) | 212 | 200 | 160 | --- |
| Continuous Rating (kW) | 8,800 | 9,600 | 3,260 | (1.5 kA) |
| One-Hour Rating (kW) | 10,400 | --- | --- | --- |

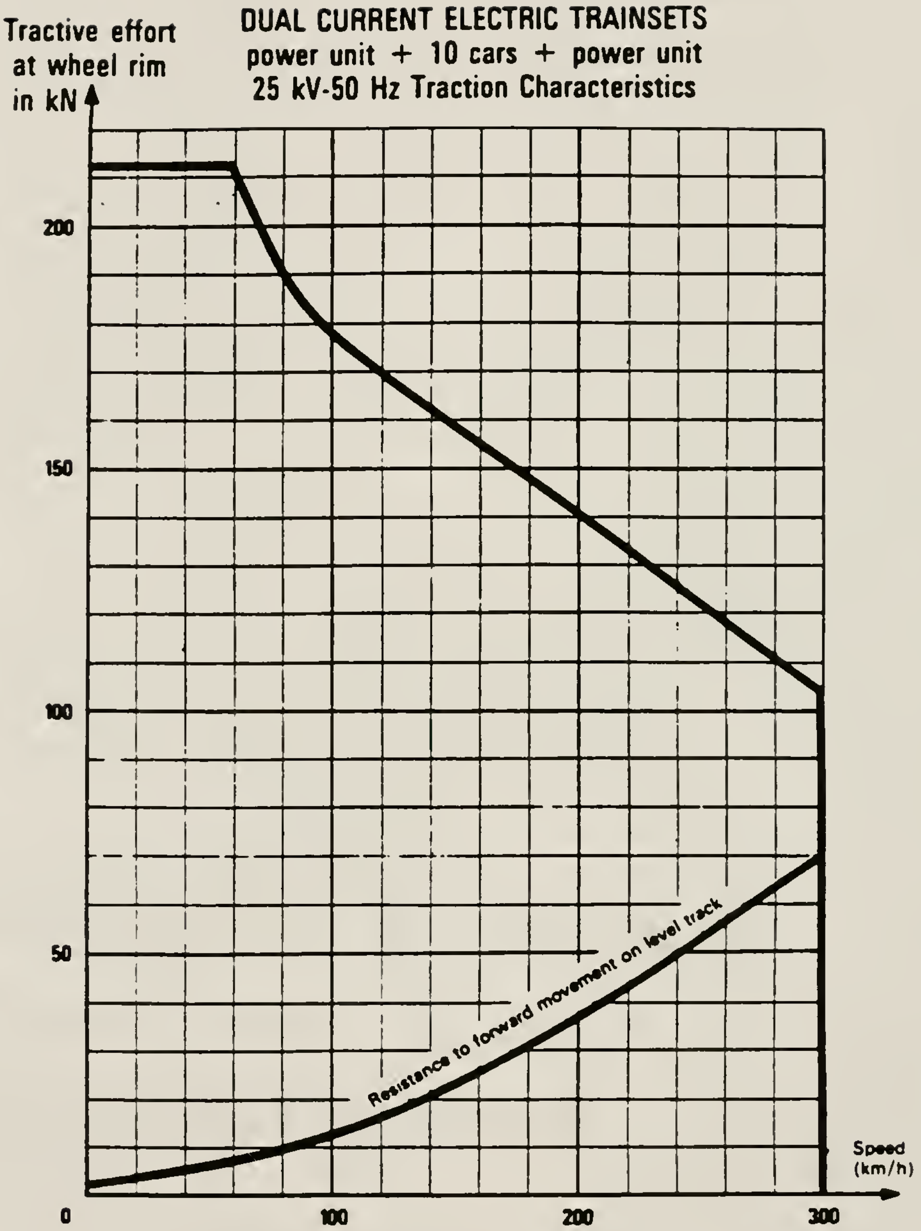


Figure 5-2: Tractive Effort and Total Resistance of TGV-A
Source: Lacote, 1986.

For the train to move forward, its tractive effort ($F_e$) must be greater than the total resistance ($F_t$), which consists of the sum of all resistive forces described earlier in this section. These forces are illustrated in Figure 5-3. From Newton's second law, the train's acceleration is described by the following equation (in SI units):

$$a = \frac{F_e - F_t}{M}$$

Where: $a$ = acceleration ($m/s^2$)

$F_e$ = tractive effort (N)

$F_t$ = total resistance (N)

$M$ = train's weight (Kg)

The tractive power vs. speed curve and the tractive resistance vs. speed curve for high performing electric motors are always given by the manufacturers. The first curve is based on too many factors to be derived with generic equations. Such equations cannot account for all the specific characteristics of the motor. This tractive power curve is generated by extensive experimentation and tempered by safety considerations. The curve cannot be fitted with one equation because higher power ratings are allowed at start-up and the tractive power drops rapidly at very high speeds. One way to describe it with equations is to divided the curve into several segments, and apply a curve fitting method for each segment (the first segment is typically a straight line equivalent to the starting power).

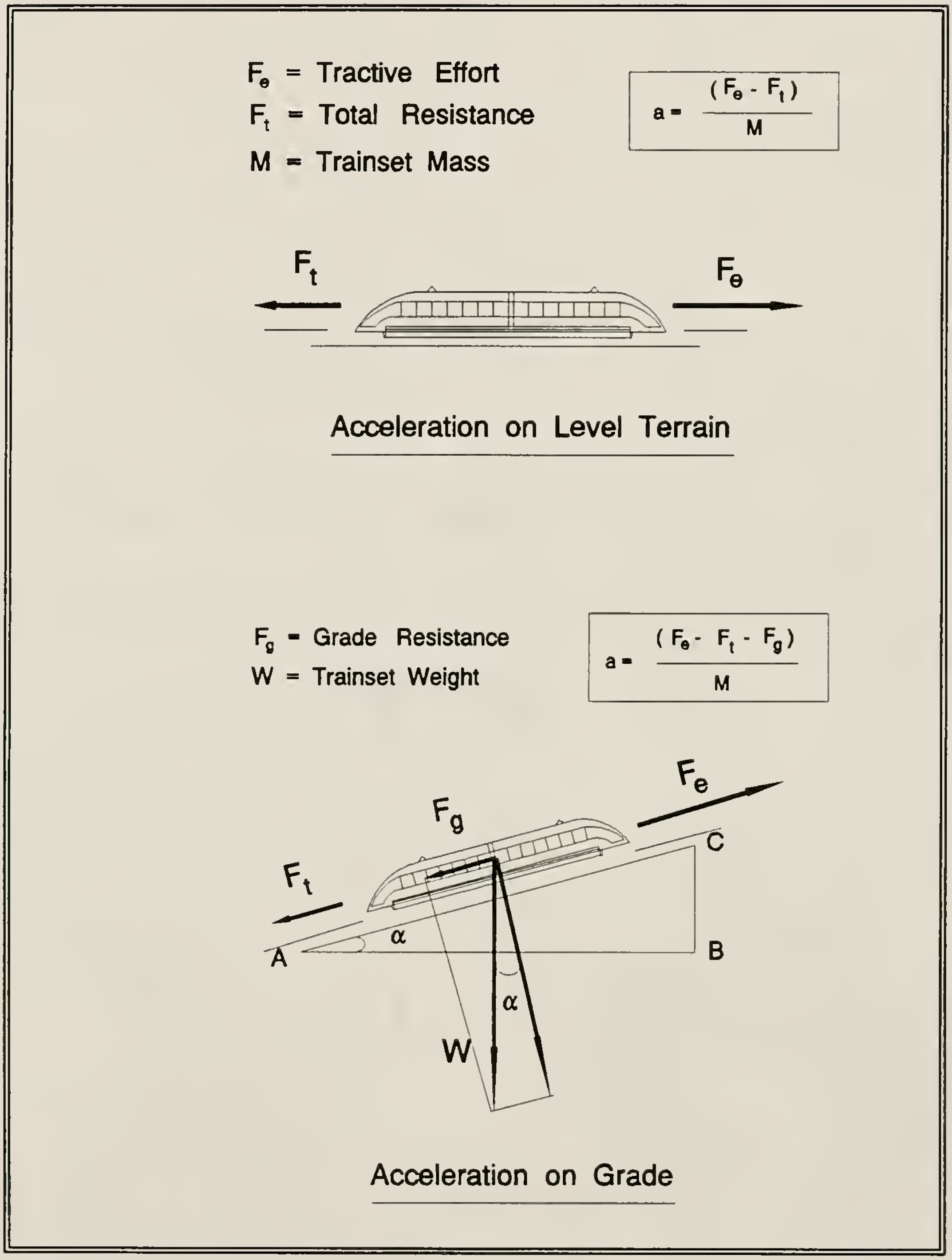


Figure 5-3: Train Acceleration on Level Terrain and Grades

As previously mentioned, the total resistance curve can be expressed with a quadratic equation of type $F_t = A + BV + CV^2$. Subtracting the total resistance curve from the tractive power curve and dividing the result by the train's mass provides the acceleration vs. speed curve. The acceleration rate of change is not uniform because the tractive power rate of change is not uniform, especially at low and very high speeds. The acceleration rate, however, can be considered as uniform over small speed increments of about 50 km/h.

Power is work divided by unit time. Work (W) is equal to the force multiplied by distance (L). By equating work ($W=F_t x L$) with the kinetic energy ($E_c=1/2\ MV^2$), it is possible to compute the force ($F_t=MV^2/2L$) necessary to accelerate a train from rest to a speed V, or the additional force ($F_{t2}-F_{t1}$) needed to accelerate from $V_1$ to $V_2$. Multiplying the required force with the traveled distance and dividing it by the duration provides an estimate of the necessary tractive power. However, because the acceleration rate can be assumed constant only over small speed increments, computing the power required should be performed per small speed increments.

Therefore, for small speed increments, the force F necessary to accelerate a train of mass M from speed $V_1$ to speed $V_2$ over a distance L is given by the equation (all units should be consistent):

$$F = \frac{M\ (V_2^2 - V_1^2)}{2L}$$

The distance L necessary to accelerate a train from speed $V_1$ to speed $V_2$ can be derived from the previous equation as follows:

$$L = \frac{M(V_2^2 - V_1^2)}{2F}$$

For simulation purposes, however, the tractive force and the tractive resistance curve are only used to estimate the system's acceleration rates in relation to speed. Travel time and end-segment speed are computed for small distances using basic dynamic relationships that assume a uniform acceleration per small speed increments.

## Acceleration on Grades

Grades add a new resistive force ($F_g$) that should be overcome by the tractive force ($F_t$). Railroad grades are measured in percent. The weight vector of the train can be separated into a normal component and a parallel component. The grade resistance ($F_g$) is the component of the weight vector that is parallel to the track as shown in Figure 5-3. If the train climbs a grade section, the grade resistance acts as an additional resistive force. On downhill slopes, the component of the weight parallel to the track increases the acceleration rate, which should not exceed the comfort limits.

$F_c$ = Centifugal Force Due to the Curved Path

$F_c'$ = Component of Centrifugal Force

$F_s$ = Balancing Force Due to Weight Component

$F_u$ = Unbalanced Force That Causes Lateral Acceleration

$\alpha$ = Track Superelevation (Degrees)

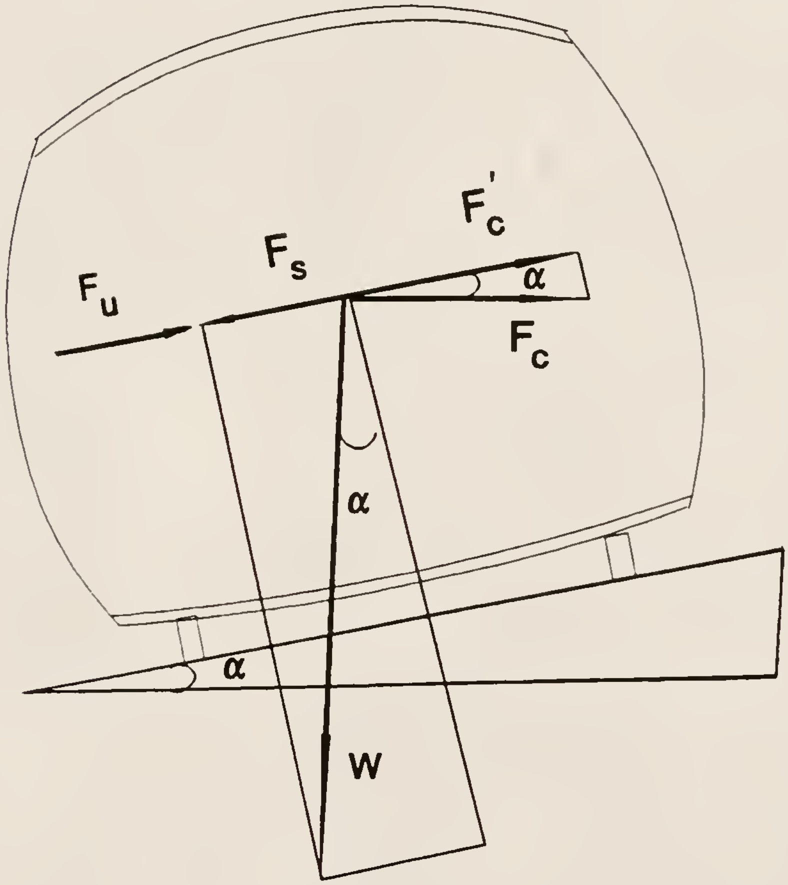


Figure 5-4: Forces Acting on a Train Traveling on a Curve

From similar triangles $F_g$ can be derived as:

$$F_g = \frac{BC}{AC} W = W \sin \alpha$$

For small angles:

$$\sin \alpha \cong \tan \alpha = p$$
$$F_g = W . p$$

Where: p = $\tan \alpha$ = BC/AB = percent grade
W = train's weight (N).

The acceleration of a train on a grade section is described by the following general equation:

$$a_g = \frac{F_e - F_t \mp F_g}{M}$$

Where: $a_g$ = acceleration on grade ($m/s^2$)
M = train's mass (Kg)
$F_e$ = tractive effort (N)
$F_t$ = total resistance (N)
$F_g$ = grade resistance (positive uphill).

If the simulation process uses uniform acceleration rates per small speed increments (instead of deriving acceleration rates from tractive and resistive forces), the impact of grade resistance on the corresponding acceleration rate is estimated as follows:

$$a_g = \frac{F_e - F_t \mp F_g}{M}$$

$$a_g = \frac{F_e - F_t}{M} \mp \frac{F_g}{M}$$

$$a_g = a \mp \frac{W \sin \alpha}{M}$$

$$a_g = a \mp \frac{M\, g \sin \alpha}{M}$$

$$a_g \cong a \mp g\,.\,p$$

Where: $a_g$ = acceleration on grade ($m/s^2$)

$a$ = acceleration on level terrain ($m/s^2$)

$p$ = percent grade ($\tan \alpha = \sin \alpha$ for small grades)

$g$ = acceleration due to gravity ($9.81\ m/s^2$).

Grades for freight trains are generally limited to one percent. Freight trains travel at low speeds and quickly loose speed on steeper grades. The HSR trains, however, can operate on up to 5% grades and maglev trains can climb 10% grades. This is because electric motors are more powerful and weigh less than the diesel-electric motors used in freight trains. Furthermore, an HSR or maglev train traveling at high speed stores a kinetic energy that rises with the square of the speed. On uphill grades, the kinetic energy is transformed into potential energy that serves to overcome the force of gravity. By equating the kinetic energy ($E_c$) and the potential energy ($E_p$), it is possible to compute the reduction in speed on uphill grades.

$$E_c = E_p$$

$$\frac{M\,(V_2^2 - V_1^2)}{2} = Mgh$$

$$V_2^2 = \sqrt{V_1^2 - 2gh}$$

Where: g = acceleration due to gravity (9.81 m/s²)

h = elevation (m)

V = speed (m/s).

For instance, if a train is traveling at 280 km/h (77.78 m/s) and then climbs a three percent grade section, its speed drops only by 0.5% to 278.6 km/h (77.4 m/s) in 100 meters, and drops by 5.0% to 266 km/h (73.9 m/s) in 1000 meters. On the hand, if the traveling speed is 100 km/h (27.78 m/s) and then the train climbs a three percent grade, its speed drops by 3.9% to 96.1 km/h (26.7 m/s) in 100 meters, and drops by 51.2% to 48.8 km/h (13.55 m/s) in 1000 meters. In both cases it was assumed that the train's tractive power is utilized to overcome its tractive resistance.

These calculations indicate that selecting the length of the grade section is as important as selecting the section's gradient. Therefore, the maximum allowable gradient should only be used on short sections of the route, preferably on sections where the train operates at high speed.

## Allowable Speed on Curves

A train traveling around a curve is subject to a centrifugal force ($F_c$) acting at the train's center of gravity and directed radially outward. From dynamics, this force equals:

$$F_c = \frac{MV^2}{R}$$

Where: $F_c$ = centrifugal force (N)

M = train's mass (Kg)

V = train's speed (m/s)

R = curve radius (m).

For near straight curves, $F_c$ is balanced by track superelevation (the outside rail of the curve is raised or superelevated a small distance above the inside rail.) The horizontal component of the weight due to superelevation creates a force ($F_s$) equal but opposite to $F_c$ as shown in Figure 5-4. There are however practical limits to track superelevation. Furthermore, on tracks designed for mixed traffic (e.g., ICE lines in Germany) the superelevation must be appropriate for slower trains. Therefore, for higher speeds or sharper curves the force $F_s$ is no longer sufficient to balance $F_c$. This causes an unbalanced lateral force directed radially outward. This force causes an unbalanced lateral acceleration ($a_1$) that can be derived from the following equations:

$$F_c = \frac{M\,V^2}{R}$$

$$F_c' = F_c \cos\alpha = \frac{M\,V^2}{R}\cos\alpha$$

$$F_s = W\sin\alpha = M\,g\sin\alpha$$

$$F_u = F_c' - F_s$$

$$F_u = \frac{M\,V^2}{R}\cos\alpha - M\,g\sin\alpha$$

$$a_l = \frac{F_u}{M} = \frac{V^2}{R}\cos\alpha - g\sin\alpha$$

Where: $F_c$ = centrifugal force (N)

$F_s$ = balancing force due to superelevation (N)

$F_u$ = unbalanced force in (N)

R = curve radius (degrees)

$\alpha$ = angle of superelevation (degrees)

$a_1$ = lateral acceleration ($m/s^2$)

W, M, g, and V as previously defined.

From the previous equations, the maximum curve speed for a given superelevation angle $\alpha$ (in degrees) and an allowable lateral acceleration $a_1$ (in $m/s^2$) can be derived as follows:

$$V = \sqrt{\frac{R\,(a_l + g\sin\alpha)}{\cos\alpha}}$$

Where: V = maximum curve speed (m/s)

R, $a_1$, $\alpha$ and g as previously defined.

The speed at which no lateral acceleration is generated ($a_1 = 0$ and $F_s = F'_c$) is calculated as:

$$V = \sqrt{\frac{R\ g \sin\alpha}{\cos\alpha}} = \sqrt{R\ g \tan\alpha}$$

Some trains such as the Swedish X-2000 and the Italian ETR 450 are equipped with a tilt mechanism that reduces the unbalanced lateral acceleration. From a dynamic perspective, each degree of effective tilt ($\phi$) has a similar impact as a degree of track superelevation ($\alpha$). The effective tilt angle ($\phi$) is shown in Figure 5-5. The maximum curve speed for a tilt train is therefore:

$$V = \sqrt{\frac{R\ (a_1 \ + \ g \sin(\alpha + \phi)}{\cos(\alpha + \phi)}}$$

Where: V = maximum curve speed (m/s)

$\phi$ = effective tilt angle (degrees)

R, $a_1$, $\alpha$ and g as previously defined.

Before the FRA adopted the SI units, track superelevation, lateral acceleration and effective tilt were all measured in inches. The sum of all these values was known as the total superelevation, which was also measured in inches. Unbalanced superelevation was determined by calculating the additional track superelevation that will balance the lateral acceleration. The tilt superelevation was derived from trigonometry and the standard rail gauge. The lateral acceleration was referred to as unbalanced superelevation and the effective tilt angle was referred to as superelevation tilt.

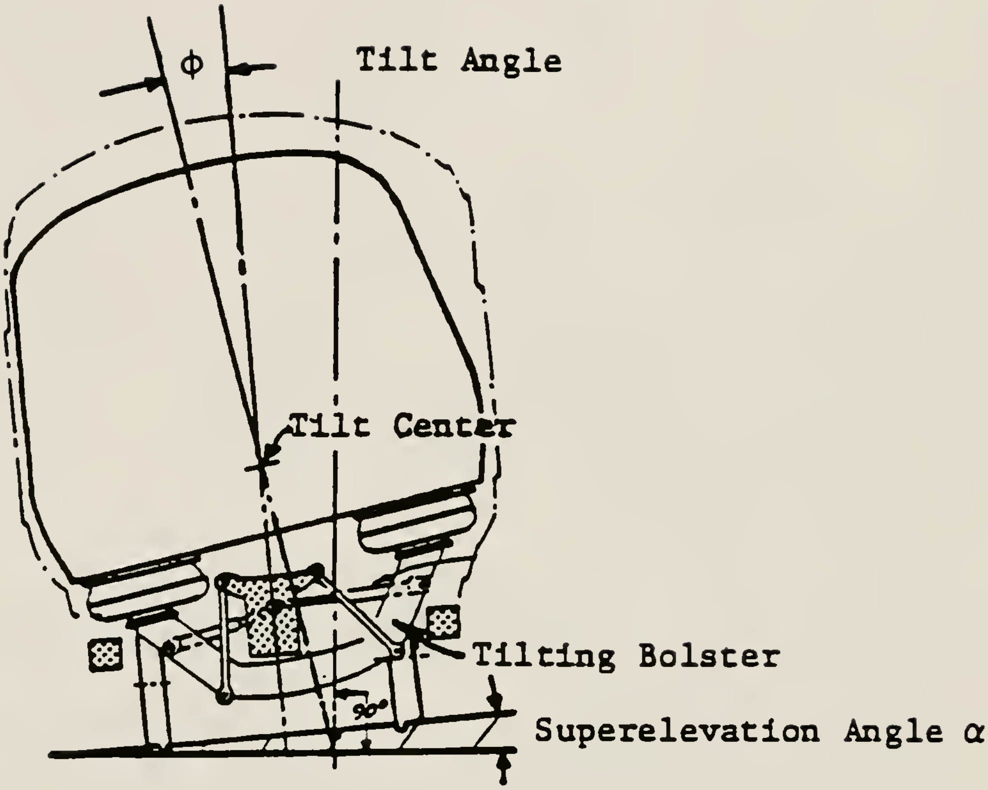


Figure 5-5: Car Body Tilt Angle of a Tilting Train
Source: Petersen, 1985.

The equation expressed in U.S. units previously approved by FRA to find the maximum allowable speed is (FRA, 1975):

$$V = \sqrt{\frac{e_{total}}{0.00069\ D}}$$

Where: V = maximum speed (mph)

$e_{total}$ = total superelevation measured in inches

= track + unbalanced + tilt superelevations

D = degree of curve (=5730/radius in feet).

Past FRA regulations recommended a maximum track superelevation of 6 in and an unbalanced superelevation of 3 in. These values are not applicable to HSGT systems. Maglev systems have better suspensions and can accommodate higher track superelevations. Further, because maglev systems do not use the U.S. standard gauge, track superelevation and effective tilt should not be measured in inches. They should be expressed in degrees and unbalanced superelevation should be expressed in acceleration units ($m/s^2$ or g).

Many railroad engineers still prefer to express lateral acceleration in equivalent inches. A lateral acceleration of 0.1 g (g=acceleration due to gravity) is usually approximated with 6 in of unbalanced superelevation. This approximation, however, is not exact. It requires assumptions only valid for small angles and low acceleration rates.

The only accurate method to express lateral acceleration as an unbalanced superelevation (inches or degrees) is to compute the allowable speed for selected values of lateral acceleration and track superelevation, and then assume the acceleration equals zero and compute the equivalent track superelevation in degrees that provides the same allowable speed. Using trigonometry and knowing the track width, the unbalanced superelevation in degrees can be translated into inches or centimeters. This process must be repeated for all desired combinations of lateral acceleration and track superelevation. In this study, two spreadsheet programs were developed by the author to compute these values for various combinations of lateral acceleration and track superelevation. The results for HSR systems are presented in Table 5-2 and for Transrapid are presented in Table 5-3.

### Transitional Spiral Curves

The transition between straight and curved sections of the route is accomplished with spiral transitional curves. The clothoid and sinusoid spiral transition curves are appropriate for HSGT systems (Carlton et al., 1992). These curves reduce the jerk rate (rate of change of acceleration measured in g/s where g is acceleration due to gravity) and the roll rate (rate of change od curvature measured in degrees per second).

The clothoid curve is based on constant rate of change in lateral acceleration throughout the spiral length. The length of the clothoid curve ($L_c$) is given by the equation:

$$L_c = \frac{V^3}{R\,r_y}$$

Where: $L_c$ = clothoid spiral length (m)

$V$ = speed in m/s

$R$ = curve radius (m)

$r_y$ = lateral jerk ($m/s^2/s$ or g/s).

The sinusoid curve is based on a gradual rate of change in lateral acceleration throughout the spiral length. It provides a smoother ride, more acceptable to passengers (Carlton et al., 1992). The length of the sinusoid curve ($L_s$), however, is twice as long as that of the clothoid. The length is given by the equation:

$$L_s = 2\,\frac{V^3}{R\,r_y}$$

Where: V, R and $r_y$ are as previously defined.

## Vertical Curves

Limiting speed on vertical curves was not a major concern for freight trains because the travel speed was low and the maximum gradient was about one percent. The situation is quite different for HSR and especially for maglev systems. Higher operating speeds and allowable grades require examining the vertical accelerations generated by traveling over vertical grades. Tests have shown that passengers are very sensitive to upward unbalanced accelerations (Carlton and Andriola, 1992). However, more experiments are needed to study the impacts of vertical acceleration on passenger comfort and ride quality as well as the counterbalancing effect of the dampening and suspension systems.

Vertical transitional curves are also used to smooth the transition between grade sections and reduce jerk rates. Several computer programs have been developed to assist in the design and layout of vertical and horizontal curves, such as the MOSS software (Bender, 1990) developed in Holland, and the Fer-Line computer package (Brancatelli et al., 1990) developed in Italy.

Table 5-2: Relationship Between Lateral Acceleration and Unbalanced Superelevation for HSR Systems

| Track Sup. (deg) | Unit | Lateral Acceleration (m/s2) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 0.20 | 0.40 | 0.60 | 0.80 | 1.00 | 1.20 | 1.40 | 1.60 |
| 4 | cm | 2.92 | 6.21 | 8.69 | 11.55 | 14.38 | 17.19 | 19.95 | 22.69 |
| 4 | in | 1.15 | 2.44 | 3.42 | 4.55 | 5.66 | 6.77 | 7.86 | 8.93 |
| 4 | deg | 1.14 | 2.28 | 3.41 | 4.54 | 5.67 | 6.78 | 7.88 | 8.98 |
| 6 | cm | 2.89 | 5.76 | 8.61 | 11.43 | 14.22 | 16.97 | 19.69 | 22.36 |
| 6 | in | 1.14 | 2.27 | 3.39 | 4.50 | 5.60 | 6.68 | 7.75 | 8.80 |
| 6 | deg | 1.14 | 2.27 | 3.40 | 4.52 | 5.63 | 6.73 | 7.83 | 8.90 |
| 8 | cm | 2.87 | 5.70 | 8.51 | 11.28 | 14.03 | 16.73 | 19.39 | 22.00 |
| 8 | in | 1.13 | 2.25 | 3.35 | 4.44 | 5.52 | 6.58 | 7.63 | 8.66 |
| 8 | deg | 1.13 | 2.26 | 3.38 | 4.49 | 5.58 | 6.68 | 7.76 | 8.82 |
| 10 | cm | 2.83 | 5.63 | 8.39 | 11.12 | 13.80 | 16.44 | 19.03 | 21.59 |
| 10 | in | 1.11 | 2.22 | 3.30 | 4.38 | 5.43 | 6.47 | 7.49 | 8.50 |
| 10 | deg | 1.13 | 2.24 | 3.35 | 4.45 | 5.53 | 6.62 | 7.68 | 8.73 |
| 12 | cm | 2.79 | 5.54 | 8.26 | 10.92 | 13.54 | 16.12 | 18.65 | 21.14 |
| 12 | in | 1.10 | 2.18 | 3.25 | 4.30 | 5.33 | 6.35 | 7.34 | 8.32 |
| 12 | deg | 1.12 | 2.23 | 3.32 | 4.41 | 5.48 | 6.55 | 7.58 | 8.62 |
| 14 | cm | 2.74 | 5.44 | 8.10 | 10.70 | 13.26 | 15.77 | 18.23 | 20.63 |
| 14 | in | 1.08 | 2.14 | 3.19 | 4.21 | 5.22 | 6.21 | 7.18 | 8.12 |
| 14 | deg | 1.11 | 2.21 | 3.29 | 4.36 | 5.42 | 6.46 | 7.50 | 8.51 |
| 16 | cm | 2.69 | 5.33 | 7.93 | 10.47 | 12.95 | 15.39 | 17.76 | 20.10 |
| 16 | in | 1.06 | 2.10 | 3.12 | 4.12 | 5.10 | 6.06 | 6.99 | 7.91 |
| 16 | deg | 1.10 | 2.18 | 3.26 | 4.31 | 5.35 | 6.38 | 7.39 | 8.38 |

Standard HSR Gauge = 1.44 m (4.708 ft)
Difference in elevations is measured between inside and outside rails

Table 5-3: Relationship Between Lateral Acceleration and Unbalanced Superelevation for Transrapid Maglev System.

| Track Sup. (deg) | Unit | Lateral Acceleration (m/s2) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 0.20 | 0.40 | 0.60 | 0.80 | 1.00 | 1.20 | 1.40 | 1.60 |
| 4 | cm | 5.93 | 12.63 | 17.69 | 23.50 | 29.26 | 34.97 | 40.60 | 46.18 |
| 4 | in | 2.34 | 4.97 | 6.96 | 9.25 | 11.52 | 13.77 | 15.98 | 18.18 |
| 4 | deg | 1.16 | 2.32 | 3.47 | 4.62 | 5.77 | 6.90 | 8.02 | 9.14 |
| 6 | cm | 5.89 | 11.73 | 17.52 | 23.26 | 28.94 | 34.54 | 40.07 | 45.50 |
| 6 | in | 2.32 | 4.62 | 6.90 | 9.16 | 11.39 | 13.60 | 15.77 | 17.91 |
| 6 | deg | 1.16 | 2.31 | 3.46 | 4.60 | 5.73 | 6.85 | 7.97 | 9.06 |
| 8 | cm | 5.83 | 11.61 | 17.32 | 22.96 | 28.54 | 34.03 | 39.45 | 44.77 |
| 8 | in | 2.30 | 4.57 | 6.82 | 9.04 | 11.24 | 13.40 | 15.53 | 17.63 |
| 8 | deg | 1.15 | 2.30 | 3.44 | 4.57 | 5.68 | 6.79 | 7.90 | 8.98 |
| 10 | cm | 5.76 | 11.46 | 17.08 | 22.62 | 28.08 | 33.46 | 38.72 | 43.94 |
| 10 | in | 2.27 | 4.51 | 6.72 | 8.91 | 11.06 | 13.17 | 15.25 | 17.30 |
| 10 | deg | 1.15 | 2.28 | 3.41 | 4.53 | 5.63 | 6.73 | 7.81 | 8.88 |
| 12 | cm | 5.68 | 11.28 | 16.80 | 22.22 | 27.56 | 32.81 | 37.94 | 43.01 |
| 12 | in | 2.24 | 4.44 | 6.61 | 8.75 | 10.85 | 12.92 | 14.94 | 16.93 |
| 12 | deg | 1.14 | 2.26 | 3.38 | 4.49 | 5.58 | 6.66 | 7.71 | 8.77 |
| 14 | cm | 5.58 | 11.07 | 16.48 | 21.78 | 26.98 | 32.09 | 37.10 | 41.98 |
| 14 | in | 2.20 | 4.36 | 6.49 | 8.57 | 10.62 | 12.63 | 14.61 | 16.53 |
| 14 | deg | 1.13 | 2.24 | 3.35 | 4.44 | 5.51 | 6.58 | 7.63 | 8.66 |
| 16 | cm | 5.47 | 10.85 | 16.13 | 21.30 | 26.36 | 31.32 | 36.15 | 40.90 |
| 16 | in | 2.15 | 4.27 | 6.35 | 8.38 | 10.38 | 12.33 | 14.23 | 16.10 |
| 16 | deg | 1.12 | 2.22 | 3.31 | 4.38 | 5.44 | 6.49 | 7.52 | 8.53 |

Transrapid guideway width= 2.93 m (9.61 ft)
Difference in elevations is measured between edges of track

# CHAPTER 6
# OPERATIONAL SIMULATION MODEL

## Classification of Simulation Models

Simulation is a powerful tool increasingly used in planning, design, and control of complex systems. It is the process of designing a model that describes the behavior of a system, and predicts the effects of changes in the system or its methods of operation. Simulation has been described as creating the essence of reality without ever actually attaining that reality itself (Phillips et al., 1976). According to Schriber (1987, P.5): "Simulation involves the modeling of a process or system in such a way that the model mimics the response of the actual system to events that take place over time."

Most simulation models involve one of two processes (Turner et al., 1978):

1. Uniform increment method.
2. Variable increment method.

The uniform increment method assumes constant time intervals, and simulates the system accordingly. Time intervals vary in the variable increment method. Simulations of moving objects often rely on constant distance intervals and variable time increments that depend on speed.

Simulation models can be described in different ways. According to Pegden, Shannon and Sadowski (1990), simulation models can be classified as:

1. Symbolic vs. iconic.
2. Deterministic vs. stochastic.
3. Dynamic vs. static.
4. Discrete vs. continuous vs. combined.

Symbolic simulation models are those in which the properties and characteristics of the real system are captured in mathematical forms. Iconic simulation models are interactive models used primarily for training and teaching purposes. For example, iconic simulators are being used to train pilots and to teach proper responses to computer-generated emergency situations.

Real-world systems are seldom free of random or unpredictable variables. Stochastic models attempt to capture the behavior of random components, often by using complex derivations and mathematical transformations. Deterministic models ignore this randomness, assuming it to be unimportant to the simulation objectives.

Dynamic models describe the behavior of a system through time. Static models simulate the behavior of a system at a single point in time. To illustrate the difference, a model that computes the profit at the end of the year is a static one, whereas a dynamic model simulates profit variation throughout the year period. Spreadsheet programs are often used to simulate static models. Computer modeling programs are necessary to simulate dynamic systems.

The final classification is related to the manner in which the model represents changes of state within the system modeled. If changes in the status of the system are simulated at isolated points in time, the model is described as discrete. If changes are modeled continuously using algebraic or differential equations, then the model is continuous. If some variables are simulated continuously and others at constant intervals, then the process is described as a combined model.

According to these classifications, the model developed to simulate the operation of HSR and maglev system uses the variable increment method, and can be classified as symbolic, deterministic, dynamic and discrete.

### Purpose of the Operational Simulation Model

The purpose of the operational model is to provide a simplified and quick method to simulate the movement of an HSR or maglev train along a route and to develop relationships between speed, acceleration, distance and travel time. These relationships are used to compute the travel time and the average speed of trips between stations and for the entire route. Furthermore, the model estimates energy consumption and noise emission rates for each segment of the route. Finally, the model can easily evaluate the impact of changes in technology, performance parameters, route alignment, passenger comfort criteria, and addition or deletion of stations.

The operational model provides a simplified and easy-to-use simulation process for four reasons:

1. The model contains default technical parameters for the four HSR and maglev technologies considered for implementation in the United States.
2. Menus are provided to simplify data input.
3. All route data are included into one ASCII file.
4. Default values for track superelevation and allowable lateral acceleration are entered just once in the main menu. Only nontypical values need to be included in the route data file. This not only simplifies the input process but also provides a quicker way to perform sensitivity analysis.

## Inputs to the Model

The model's input parameters are divided into four groups. The first two groups are reserved for technical parameters. Groups three and four are what constitute the route data file. These groups are:

1. Performance characteristics.
2. Passenger comfort criteria.
3. Route alignment.
4. Station locations.

The required technical parameters consist of acceleration and deceleration rates and maximum speed. The optional technical parameters consist of energy consumption, noise emission, tilt rate, and allowable maximum grade. Default performance parameters for four technologies and 14 systems are included in the model. In addition, the model allows the user to define any new HSR or maglev system, be it real or hypothetical.

Passenger comfort criteria consist of six technology dependent parameters:

1. Maximum track superelevation (or banking angle).
2. Maximum unbalanced lateral acceleration.
3. Maximum unbalanced upward acceleration.
4. Maximum unbalanced downward acceleration.
5. Maximum unbalanced longitudinal acceleration.
6. Maximum unbalanced longitudinal deceleration.

The comfort-limit longitudinal accelerations are never exceeded by existing systems (USDOT, 1992). Therefore, they are ignored in operational simulations.

The route alignment parameters consist of vertical and horizontal curvatures, grade segments, speed restrictions, and station locations. Curves are described by location, length, curve radius, and track superelevation. Grade segments are described by location, length and percent gradient. Externally imposed speed restrictions result from track conditions, noise levels, bridges, overpasses, tunnels, or other reasons. They are described by location, length, and speed limit. Stations are described by location and dwell time.

In a route file, stations are entered first, then grade segments, followed by curves and finally speed-restriction segments. Each entry occupies one line of the file. The input file is formatted. All decimals must be located at the appropriate columns. Entries are real numbers with three significant decimals. Because of the formatted input, a zero value or a default value needs not be entered, and there is no need to separate entries with commas. Furthermore, columns 54 to 80 of all input lines are ignored by the program and can be used for comments. Figure 6-1 illustrates a few input lines of a hypothetical route file. The route files for the case studies are included in Appendix C.

## Structure of the Model

The operational model consists of two programs. All calculations are performed in a program written in FORTRAN and listed in Appendix A. The simulation process requires extensive computations with floating numbers and FORTRAN is suitable for this type of analysis. The FORTRAN language, however, does not allow easy interface with the user, and is incapable of generating input menus. Therefore, menus were created using the BASIC language to provide a graphical and easy way to input data and capture input errors. The proper interaction between the FORTRAN and BASIC programs was insured by a batch file. The listing of the BASIC program is included in Appendix B. Figure 6-2 shows the first and second screens of the simulation model's menus. A third screen dealing with vertical curves will be added at a future time. The technical default data related to the HSR and maglev systems are stored in a separate file that can be updated using any ASCII-type word processor.

The simulation process consists of six steps as illustrated by the flowchart in Figure 6-3. These steps are the following:

1. System data input.
2. Route data and comfort-limit parameters.
3. Calculation of route's allowable speed profile.
4. Simulation process.
5. Simulation outputs.
6. Sensitivity analysis.

The system data input section of the model allows the user to select a technology, accept default technical values stored in the model or update them. The HSGT Systems are described by eight types of technical data: (1) maximum speed, (2) acceleration rates, (3) deceleration rates, (4) noise emission coefficients, (5) energy consumption coefficients, (6) number of sections per trainset, (7) number of passenger seats per trainset, and (8) train's effective tilt rate. Default acceleration and deceleration rates for Transrapid, TGV, ICE and X-2000 are stored per speed increments of 50 km/h. Energy consumption and noise emission depend on speed and technology. Modeling equations were developed based on data provided by manufacturers as described later in this

```
         1         2         3         4         5         6
123456789012345678901234567890123456789012345678901234567890123456789
--------------------------- TOP OF FILE ------------------------------
       34.0       3.0                                STATION#1
       58.0       2.0                                STATION#2
       15.0       3.2       1.2                      GRADE#1
       45.6       2.5      -2.2                      GRADE#2
       85.0       1.0       3.1                      GRADE#3
       28.0       3.1    2800.0       9.0       0.7  CURVE#1
       65.0       3.0    3200.0                -1.0  CURVE#2
       75.4       1.7    4000.0      -1.0            CURVE#3
       10.0       1.8     200.0                      SPEED-R.#1
       55.0       2.5     250.0                      SPEED-R.#2
       88.0       2.0     275.0                      SPEED-R.#3
--------------------------- END OF FILE ------------------------------
```

COMMENTS

1. The sample route data file contains 2 stations, 3 grade sections, 3 curves and 3 speed restrictions.
2. File is formatted, all decimals must be located on column 10, 20, 30, 40 or 50.
3. Each station is defined by location and dwell time
4. Each grade section is defined by starting location, length, and percent grade (positive uphill)
5. Curves are defined by location, length, radius, track superelevation, and lateral acceleration
6. Speed restrictions are defined by location, length, and speed limit
7. For track superelevation and lateral acceleration, a zero value means typical default and -1 means exceptional
8. Columns 54 to 80 are reserved for comments

DESCRIPTION OF SELECTED INPUT LINES

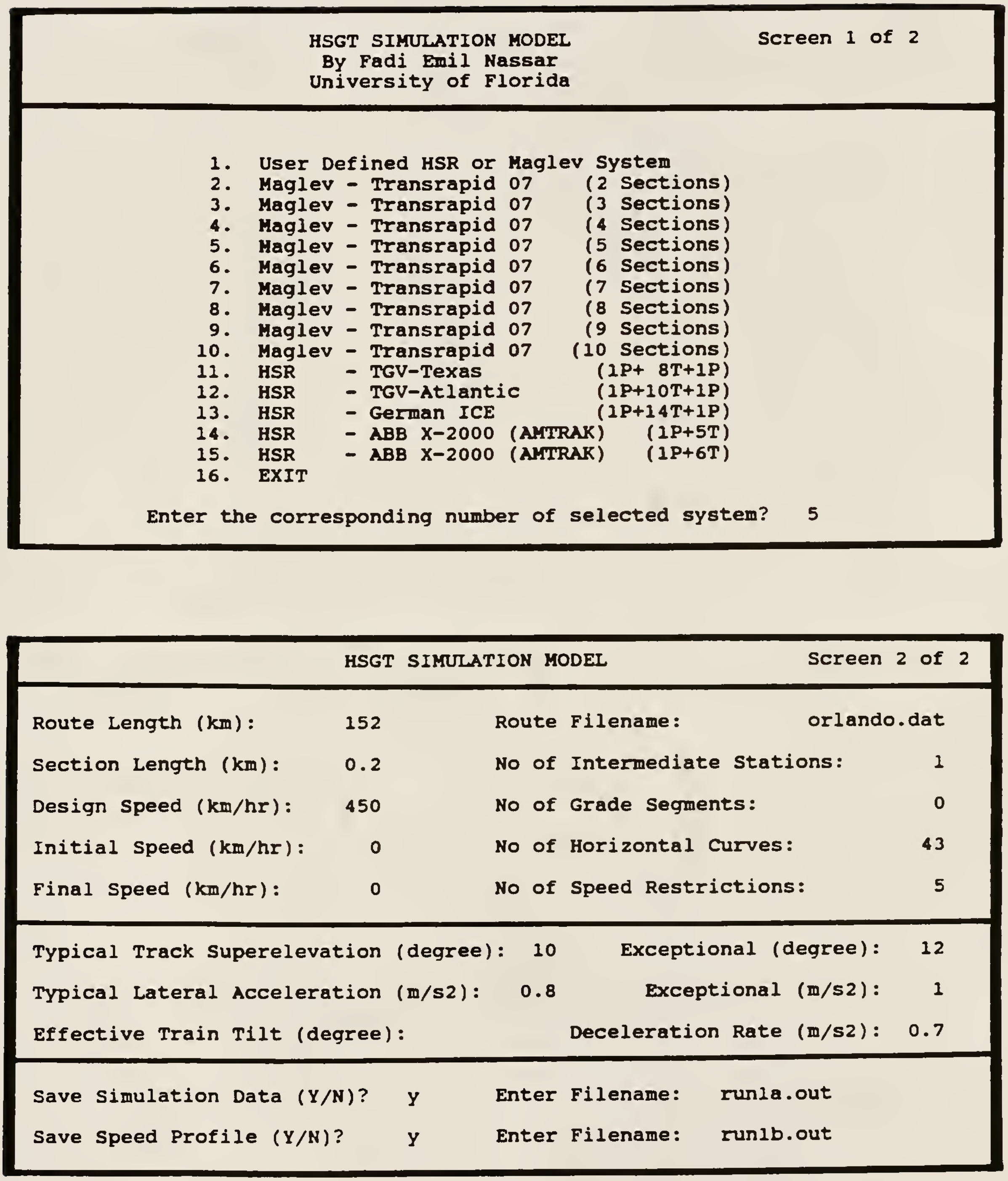
Station#1 is located at 34 km and its dwell time is 3 min

Grade#2 starts at 45.6 km, is 2.5 km long, and slope is 2.2% downhill.

Curve#3 starts at 74.4 km, is 1.7 km long, has a radius of 4000 meters, track sup. is default exceptional and allowable lateral accel. is typical

Speed limit#3 starts at 88 km, is 2 km long, max.speed iS 275 km/h.

Figure 6-1: Sample Route Data Input File



```
                  HSGT SIMULATION MODEL                 Screen 1 of 2
                  By Fadi Emil Nassar
                  University of Florida

         1.  User Defined HSR or Maglev System
         2.  Maglev - Transrapid 07    (2 Sections)
         3.  Maglev - Transrapid 07    (3 Sections)
         4.  Maglev - Transrapid 07    (4 Sections)
         5.  Maglev - Transrapid 07    (5 Sections)
         6.  Maglev - Transrapid 07    (6 Sections)
         7.  Maglev - Transrapid 07    (7 Sections)
         8.  Maglev - Transrapid 07    (8 Sections)
         9.  Maglev - Transrapid 07    (9 Sections)
        10.  Maglev - Transrapid 07   (10 Sections)
        11.  HSR    - TGV-Texas        (1P+ 8T+1P)
        12.  HSR    - TGV-Atlantic     (1P+10T+1P)
        13.  HSR    - German ICE       (1P+14T+1P)
        14.  HSR    - ABB X-2000 (AMTRAK)   (1P+5T)
        15.  HSR    - ABB X-2000 (AMTRAK)   (1P+6T)
        16.  EXIT

    Enter the corresponding number of selected system?   5
```

```
                     HSGT SIMULATION MODEL                 Screen 2 of 2

Route Length (km):         152        Route Filename:            orlando.dat

Section Length (km):       0.2        No of Intermediate Stations:         1

Design Speed (km/hr):      450        No of Grade Segments:                0

Initial Speed (km/hr):       0        No of Horizontal Curves:            43

Final Speed (km/hr):         0        No of Speed Restrictions:            5

Typical Track Superelevation (degree):  10     Exceptional (degree):     12

Typical Lateral Acceleration (m/s2):   0.8      Exceptional (m/s2):       1

Effective Train Tilt (degree):              Deceleration Rate (m/s2):   0.7

Save Simulation Data (Y/N)?   y       Enter Filename:   run1a.out

Save Speed Profile (Y/N)?     y       Enter Filename:   run1b.out
```

Figure 6-2:  First and Second Input Data Screens of the Model

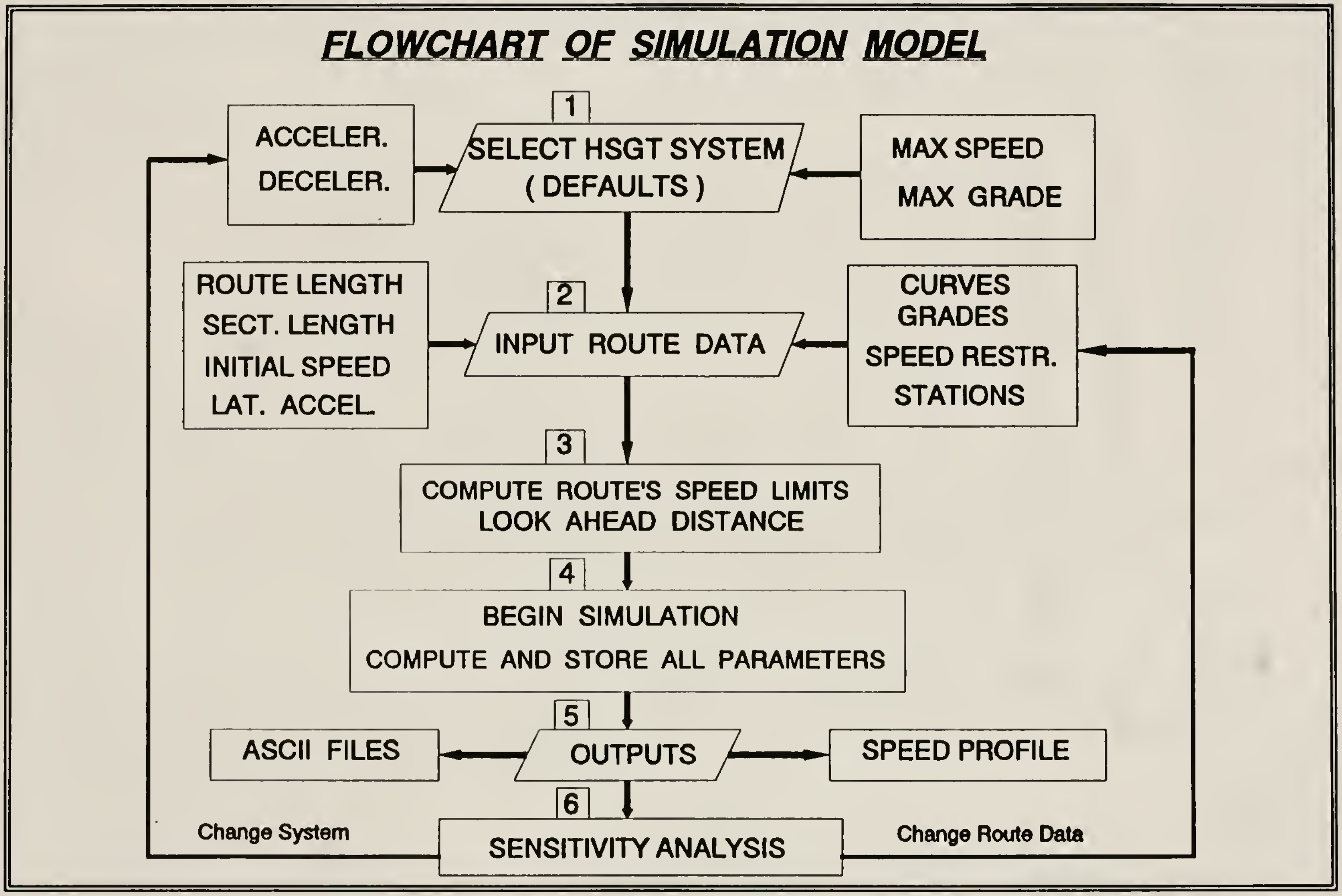


Figure 6-3: Flowchart of the Operation Simulation Model

chapter. Coefficients derived from curve fitting of available data were stored in the system file.

Route data are stored in separate ASCII files according to a predefined format as described earlier. The formatted input provides several advantages such as being able to include descriptive comments on each input line of the data file. The comfort-limit parameters are not included as default values because FRA is still studying the appropriate limits for each technology. The selected comfort-limit parameters (i.e., track superelevation, lateral acceleration, and train tilt) are input values on the second menu screen.

The model computes the allowable speed for each section of the route based on three types of data: (1) stations, (2) curves and (3) externally imposed speed limits. The allowable speed for route sections without any speed restriction is set to the train's maximum operating speed. At station locations, the section's speed limit is set to zero. For the sections located on curves, the model computes the allowable curve speed (based on track superelevation and allowable lateral acceleration as described in Chapter 5), and compares this value with any externally imposed speed restriction for the section. The lower speed is stored as the section's allowable speed. The process is repeated for all route sections. The route's allowable speed profile is illustrated by the dashed lines shown on the figures of the study cases at the end of this chapter. Grades affect the acceleration rates as described in Chapter 5 but have no impact on the route's allowable speeds.

For the simulation purpose, a route is divided into a maximum of 5000 sections. The length of each route section is selected by the user. Appropriate section lengths are between 0.1 km (328 ft) and 0.5 km (1640 ft). Acceleration and deceleration rates are assumed uniform per route section. The program stores all simulation results in a two-dimensional array. The array has 10 columns and as many rows as there are route sections. Each column of the array stores the values of a specific parameter for all route sections. These parameters and their locations in the array are the following:

Column 1: percent grade (%)
Column 2: curve radius (m)
Column 3: track superelevation (degree)
Column 4: section's allowable speed (km/h)
Column 5: simulated speed (km/h)
Column 6: section's travel time (min)
Column 7: cumulative travel time (min)
Column 8: acceleration/deceleration rate ($m/s^2$)
Column 9: noise emission (dB)
Column 10: energy consumption (kWh).

An HSR or maglev train is required to respond to changes in route conditions a long distance before it reaches them. This is because of its high speed and the stored kinetic energy. The distance needed to comfortably decelerate the train from its maximum speed to a stop is the look-ahead distance. By continuously checking the route condition as far ahead as the look-ahead distance, the train will always have adequate time to slow down comfortably to account for all speed restrictions.

In the development of the model, two simulation techniques were formulated. The first technique consists of developing a comfortable deceleration curve at each section of the route based on the train's initial speed and the look-ahead distance. The deceleration curve is extended in front of the train and compared with the route's speed restrictions as shown in Figure 6-4. At each route section, the train can take one of four possible actions: it can accelerate, decelerate, travel at constant speed, or stop. If at no point the deceleration curve intersects the route's speed limits, the train can safely accelerate for one section. If at any point the deceleration curve intersects the route's speed limits, then the appropriate acceleration or deceleration rate for that section is computed to insure that by the time the train reaches the speed restriction it does not travel at a higher speed than allowed. The train travels at a constant speed if there is no reason to decelerate and the train is already traveling at the maximum allowable speed. Finally, the train stops when reaching a station and the dwell time is added to that section's travel duration.

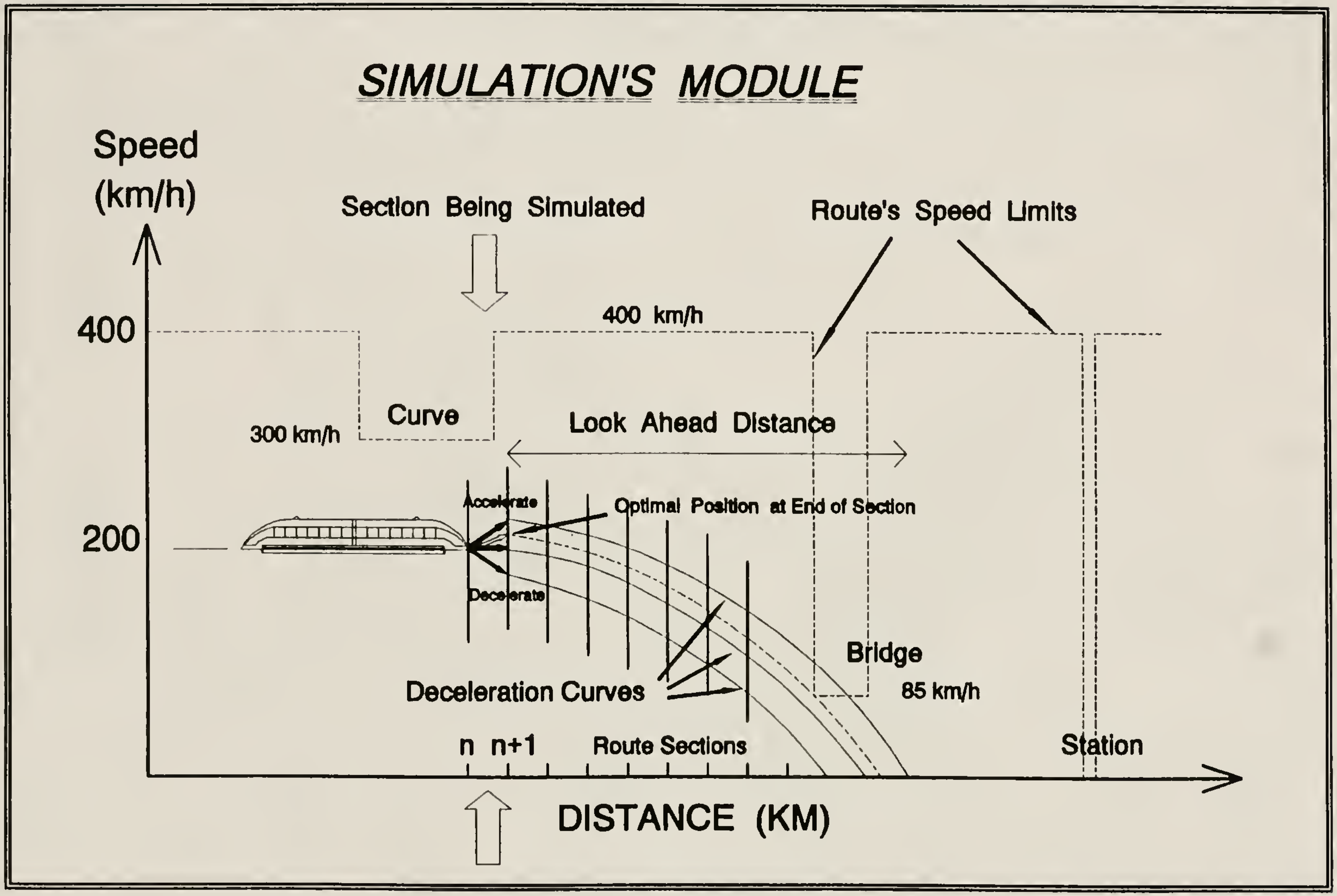


Figure 6-4: Simulation Process Using Deceleration Curves and Look-ahead Distance

This first technique produced correct results. However, it required extensive computations because a deceleration curve was generated at each route section regardless whether there was a need to decelerate or not. Another technique developed by the author proved to be equally accurate but significantly faster. The new technique consists of two steps. First, starting from the last route section and moving backward, a reversed deceleration curve was developed for each speed restriction of the route. The sum of these curves produced a backward-deceleration profile for the entire route, illustrated by the dashed lines in Figure 6-5. This backward-deceleration profile represents the maximum safe speed for each route section. By knowing the maximum safe speed, it is no longer necessary to develop deceleration curves at each route section. The train simulation process now proceeded from the first section to the last by examining route conditions only one section ahead instead of the entire look-ahead distance. To determine the mode of operation at each section, the program now simply compares the present speed with the maximum safe speed of the next section (stored in the backward speed profile coordinates) to quickly determine whether the train should accelerate, decelerate, travel at constant speed, or stop.

A number of refinements were added to the simulation process, the most important being the calculation of transitional acceleration and deceleration rates. If the train

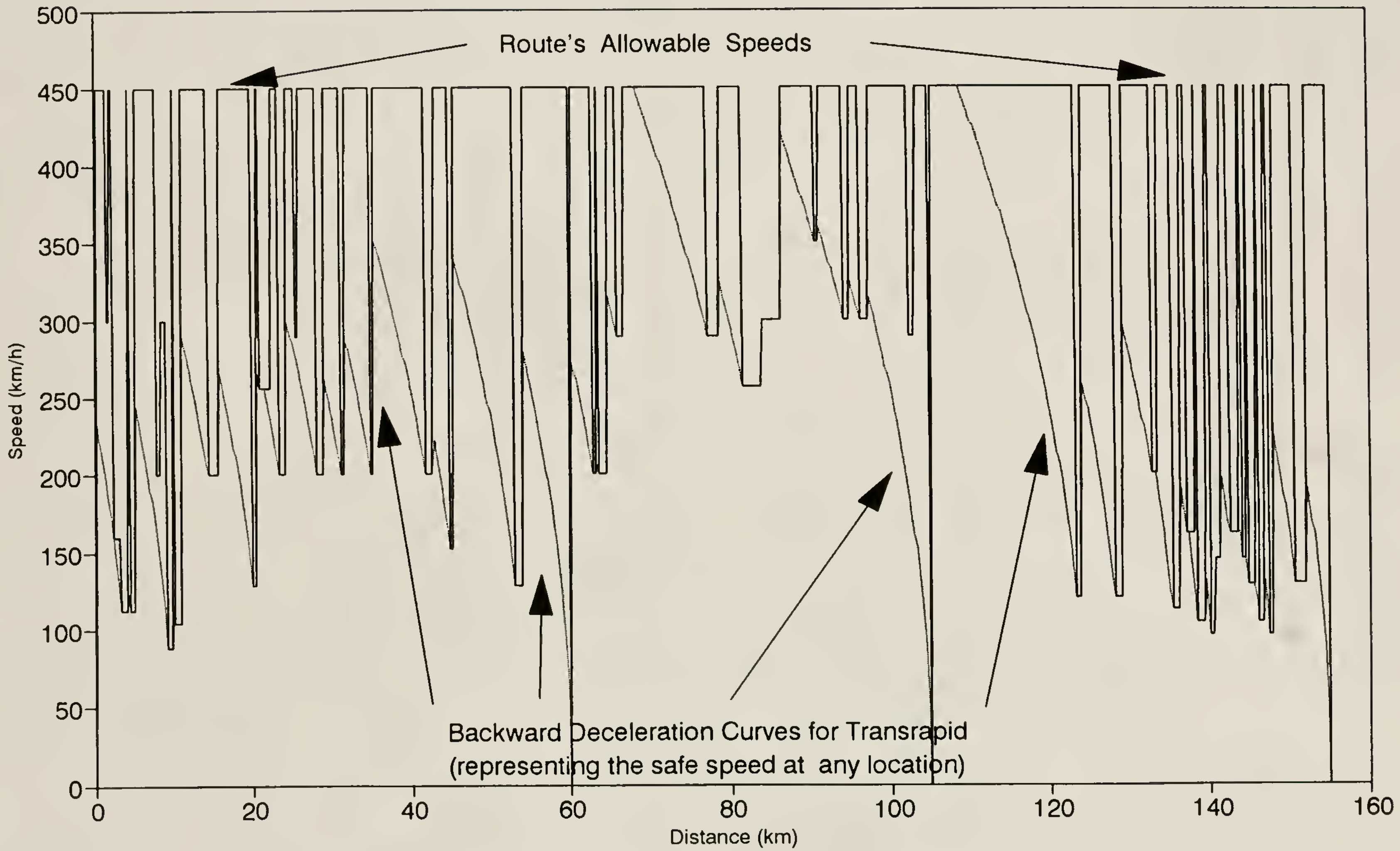


Figure 6-5: Backward Safe-Speed Curves

is accelerating and the section's final speed exceeds the allowable speed, then the final speed is set equal to the allowable speed and a transitional acceleration rate is computed. Similarly, if the train is decelerating and the final speed is lower than the section's safe speed, then the final speed is set equal to the safe speed and a transitional deceleration rate is computed. Other refinements used were mainly for the purpose of finding shortcuts to speed the simulation process and also to prohibit erratic acceleration and deceleration operations. All these refinements were satisfactorily tested and were found to produce intended results.

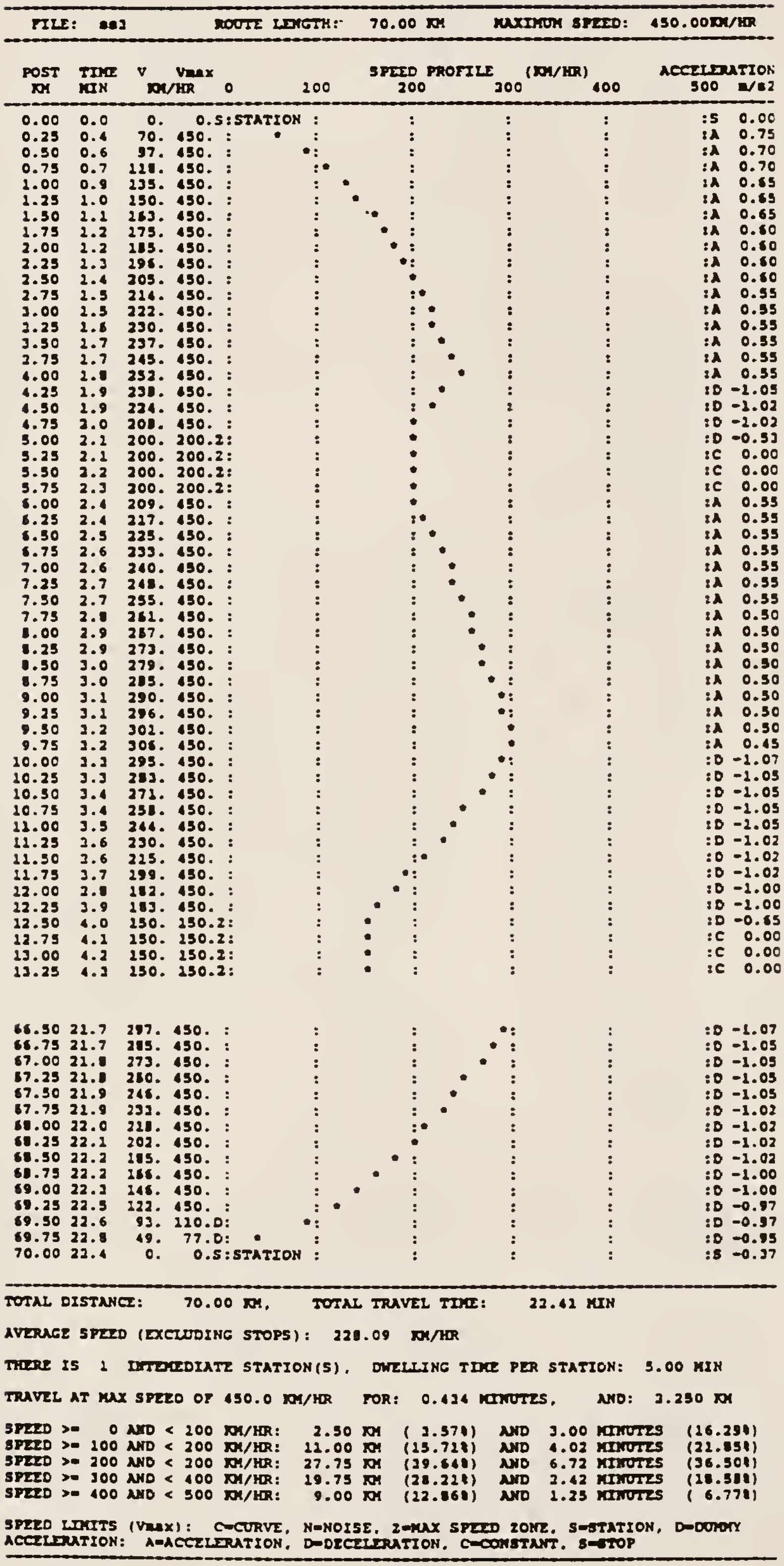
Once the mode of operation is determined for the section being simulated, all parameters for that section are computed and stored in the main matrix. These parameters include acceleration rate, travel time, section's speed, energy consumption, noise level, cumulative travel time and cumulative energy consumption. The train is then advanced one section and the entire process repeated until the last route section is reached.

The simulation results for all route segments are stored in one matrix that is retained in its entirety in the random access memory (RAM) of the computer. This provides maximum flexibility in producing useful outputs as well as summary tables. The FORTRAN program of the model generates two different output files. The first file includes a listing of all parameters for every section of the route. This file can directly be imported into a spreadsheet program to provide computer plots of selected variables from one or several runs. All the figures of the study cases described later in this chapter are generated in this manner. The second output file is a speed profile directly produced by the FORTRAN program and illustrated in Figure 6-6. The speed profile includes a summary table that provides information such as total travel time, average speed, cumulative travel distance and travel time per speed increment of 100 km/h, and total energy consumption per trainset and per seat-km. Appendix D includes a speed profile output of the FORTRAN program.

Sensitivity analysis is performed by changing the technology, route data, track superelevation rate, allowable comfort limits, or by adding or deleting stations. All these operations can be performed from the model's input menu screens.

## Collection of Technical Data

The technical data of HSR and maglev systems consist of acceleration and deceleration rates, maximum speed, maximum grade, energy consumption rates, and noise emission levels. Because only the latest systems were considered, most of the technical information was obtained directly from the European manufacturers and the railway companies that operate these systems. Some of the information received has not been published yet and therefore the data were included in the



```
--------------------------------------------------------------------------------
   FILE:  ss3         ROUTE LENGTH:   70.00 KM    MAXIMUM SPEED:  450.00KM/HR
--------------------------------------------------------------------------------

  POST  TIME  V   Vmax                SPEED PROFILE   (KM/HR)      ACCELERATION
   KM   MIN    KM/HR   0       100       200       300       400       500  m/s2
--------------------------------------------------------------------------------
  0.00  0.0    0.   0.S:STATION :         :         :         :         :S  0.00
  0.25  0.4   70. 450. :    •   :         :         :         :         :A  0.75
  0.50  0.6   97. 450. :       •:         :         :         :         :A  0.70
  0.75  0.7  118. 450. :        :•        :         :         :         :A  0.70
  1.00  0.9  135. 450. :        :  •      :         :         :         :A  0.65
  1.25  1.0  150. 450. :        :   •     :         :         :         :A  0.65
  1.50  1.1  163. 450. :        :     •   :         :         :         :A  0.65
  1.75  1.2  175. 450. :        :      •  :         :         :         :A  0.60
  2.00  1.2  185. 450. :        :       • :         :         :         :A  0.60
  2.25  1.3  196. 450. :        :        •:         :         :         :A  0.60
  2.50  1.4  205. 450. :        :         •         :         :         :A  0.60
  2.75  1.5  214. 450. :        :         :•        :         :         :A  0.55
  3.00  1.5  222. 450. :        :         : •       :         :         :A  0.55
  3.25  1.6  230. 450. :        :         : •       :         :         :A  0.55
  3.50  1.7  237. 450. :        :         :  •      :         :         :A  0.55
  3.75  1.7  245. 450. :        :         :   •     :         :         :A  0.55
  4.00  1.8  252. 450. :        :         :    •    :         :         :A  0.55
  4.25  1.9  238. 450. :        :         :  •      :         :         :D -1.05
  4.50  1.9  224. 450. :        :         : •       :         :         :D -1.02
  4.75  2.0  208. 450. :        :         •         :         :         :D -1.02
  5.00  2.1  200. 200.Z:        :         •         :         :         :D -0.53
  5.25  2.1  200. 200.Z:        :         •         :         :         :C  0.00
  5.50  2.2  200. 200.Z:        :         •         :         :         :C  0.00
  5.75  2.3  200. 200.Z:        :         •         :         :         :C  0.00
  6.00  2.4  209. 450. :        :         •         :         :         :A  0.55
  6.25  2.4  217. 450. :        :         :•        :         :         :A  0.55
  6.50  2.5  225. 450. :        :         : •       :         :         :A  0.55
  6.75  2.6  233. 450. :        :         :  •      :         :         :A  0.55
  7.00  2.6  240. 450. :        :         :   •     :         :         :A  0.55
  7.25  2.7  248. 450. :        :         :   •     :         :         :A  0.55
  7.50  2.7  255. 450. :        :         :    •    :         :         :A  0.55
  7.75  2.8  261. 450. :        :         :     •   :         :         :A  0.50
  8.00  2.9  267. 450. :        :         :     •   :         :         :A  0.50
  8.25  2.9  273. 450. :        :         :      •  :         :         :A  0.50
  8.50  3.0  279. 450. :        :         :      •  :         :         :A  0.50
  8.75  3.0  285. 450. :        :         :       • :         :         :A  0.50
  9.00  3.1  290. 450. :        :         :        •:         :         :A  0.50
  9.25  3.1  296. 450. :        :         :        •:         :         :A  0.50
  9.50  3.2  301. 450. :        :         :         •         :         :A  0.50
  9.75  3.2  306. 450. :        :         :         •         :         :A  0.45
 10.00  3.3  295. 450. :        :         :        •:         :         :D -1.07
 10.25  3.3  283. 450. :        :         :       • :         :         :D -1.05
 10.50  3.4  271. 450. :        :         :      •  :         :         :D -1.05
 10.75  3.4  258. 450. :        :         :    •    :         :         :D -1.05
 11.00  3.5  244. 450. :        :         :   •     :         :         :D -1.05
 11.25  3.6  230. 450. :        :         :  •      :         :         :D -1.02
 11.50  3.6  215. 450. :        :         :•        :         :         :D -1.02
 11.75  3.7  199. 450. :        :        •:         :         :         :D -1.02
 12.00  3.8  182. 450. :        :       • :         :         :         :D -1.00
 12.25  3.9  163. 450. :        :     •   :         :         :         :D -1.00
 12.50  4.0  150. 150.Z:        :    •    :         :         :         :D -0.65
 12.75  4.1  150. 150.Z:        :    •    :         :         :         :C  0.00
 13.00  4.2  150. 150.Z:        :    •    :         :         :         :C  0.00
 13.25  4.3  150. 150.Z:        :    •    :         :         :         :C  0.00


 66.50 21.7  297. 450. :        :         :        •:         :         :D -1.07
 66.75 21.7  285. 450. :        :         :       • :         :         :D -1.05
 67.00 21.8  273. 450. :        :         :      •  :         :         :D -1.05
 67.25 21.8  260. 450. :        :         :    •    :         :         :D -1.05
 67.50 21.9  246. 450. :        :         :   •     :         :         :D -1.05
 67.75 21.9  233. 450. :        :         :  •      :         :         :D -1.02
 68.00 22.0  218. 450. :        :         :•        :         :         :D -1.02
 68.25 22.1  202. 450. :        :         •         :         :         :D -1.02
 68.50 22.2  185. 450. :        :       • :         :         :         :D -1.02
 68.75 22.2  166. 450. :        :     •   :         :         :         :D -1.00
 69.00 22.3  146. 450. :        :   •     :         :         :         :D -1.00
 69.25 22.5  122. 450. :        : •       :         :         :         :D -0.97
 69.50 22.6   93. 110.D:       •:         :         :         :         :D -0.97
 69.75 22.8   49.  77.D:  •     :         :         :         :         :D -0.95
 70.00 22.4    0.   0.S:STATION :         :         :         :         :S -0.37
--------------------------------------------------------------------------------
TOTAL DISTANCE:     70.00 KM,    TOTAL TRAVEL TIME:     22.41 MIN

AVERAGE SPEED (EXCLUDING STOPS):  228.09  KM/HR

THERE IS  1  INTEMEDIATE STATION(S),  DWELLING TIME PER STATION:  5.00 MIN

TRAVEL AT MAX SPEED OF 450.0 KM/HR   FOR:  0.434 MINUTES,    AND:  3.250 KM

SPEED >=   0 AND < 100 KM/HR:   2.50 KM  ( 3.57%)  AND  3.00 MINUTES  (16.29%)
SPEED >= 100 AND < 200 KM/HR:  11.00 KM  (15.71%)  AND  4.02 MINUTES  (21.85%)
SPEED >= 200 AND < 300 KM/HR:  27.75 KM  (39.64%)  AND  6.72 MINUTES  (36.50%)
SPEED >= 300 AND < 400 KM/HR:  19.75 KM  (28.21%)  AND  3.42 MINUTES  (18.58%)
SPEED >= 400 AND < 500 KM/HR:   9.00 KM  (12.86%)  AND  1.25 MINUTES  ( 6.77%)

SPEED LIMITS (Vmax):  C=CURVE, N=NOISE, Z=MAX SPEED ZONE, S=STATION, D=DUMMY
ACCELERATION:  A=ACCELERATION, D=DECELERATION, C=CONSTANT, S=STOP
--------------------------------------------------------------------------------
```

Figure 6-6: Sample Output of the Operation Simulation Model

Appendices. The correspondences with Transrapid officials are included in Appendix E, the figures obtained from the French National Railway (SNCF) and related to the TGV system are included in Appendix F, various information related to the ICE system are included in Appendix G, and figures specific to the X-2000 system are included in Appendix H.

### Comfortable Acceleration Rates

A decision needed to be made on how the program computes the acceleration rates. As explained in the previous chapter, the acceleration rates can be derived from tractive and resistive forces, can be determined with modeling equations function of speed, or can be generated from the speed-distance or speed-time curve.

The tractive force's rate of change with speed is not uniform as shown in Figure 6-7. Modeling this variation requires dividing the tractive force curve into segments and describing each segment with a separate equation. Furthermore, calculations based on the tractive and resistive forces produce maximum acceleration rates which may be different from the comfortable rates. Mr. Polifka, the managing director of MVP Versuchs und Planungsgesellschaft fur Magnetbahnsysteme mbH (the company in charge of testing the Transrapid maglev system) indicated in his letters (included in Appendix E) that the acceleration rates used in normal operation are between 5% and 10% lower than the maximum rates. This helps reduce stresses on the system and save energy. Transrapid's maximum

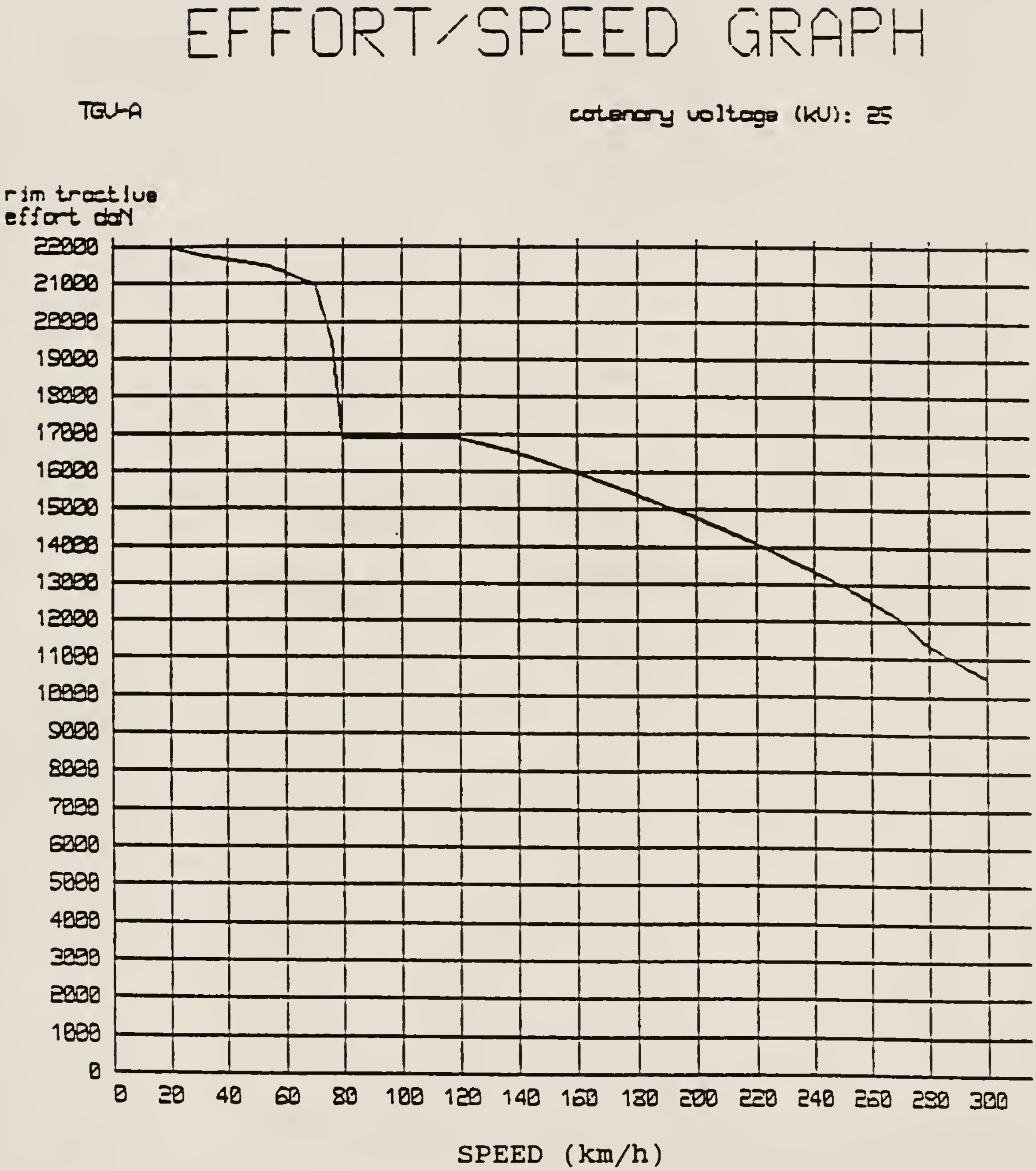


Figure 6-7: Tractive Effort Curve for the TGV-A Trainset
Source: French National Railways (SNCF)

acceleration rates would only be used on steep grades or if a train is behind schedule.

The acceleration rate at a given speed is equal to the difference between the tractive and resistive forces for that speed divided by the train's mass. The acceleration rate of change with speed is not uniform because the tractive force rate of change is not uniform. Thus, modeling the acceleration vs. speed curve is subject to the same problems as modeling the tractive force. Several equations will be needed.

Therefore, it was decided to use uniform speed increments to represent the acceleration rates. The model is designed to accept any number of uniform speed increments. After consultations with HSGT experts, a speed increment of 50 km/h (31 mph) was selected. The acceleration rate is assumed constant per speed increment.

Two spreadsheet programs were developed to compute the acceleration rates for each system. The first program was based on tractive and resistive forces as explained above. The second program computes acceleration rates from the speed-distance or speed-time profile. Measurements of distance or time coordinates are taken at 50 km/h speed increments. These measurements are typed in the assigned spreadsheet cells and the program automatically computes the acceleration rate corresponding for each speed increment. The equation used to derive the acceleration rates from the speed-distance profile is the following:

$$a = \frac{V_2^2 - V_1^2}{25920\ (d_2 - d_1)}$$

Where: a = acceleration rate for speed increment ($m/s^2$)

$V_1$ = initial speed (km/h)

$V_2$ = final speed (km/h)

$d_1$ = initial distance (km)

$d_2$ = final distance (km)

The formula used to derive the acceleration rates from the speed-time profile is the following:

$$a = \frac{V_2 - V_1}{3.6\ (t_2 - t_1)}$$

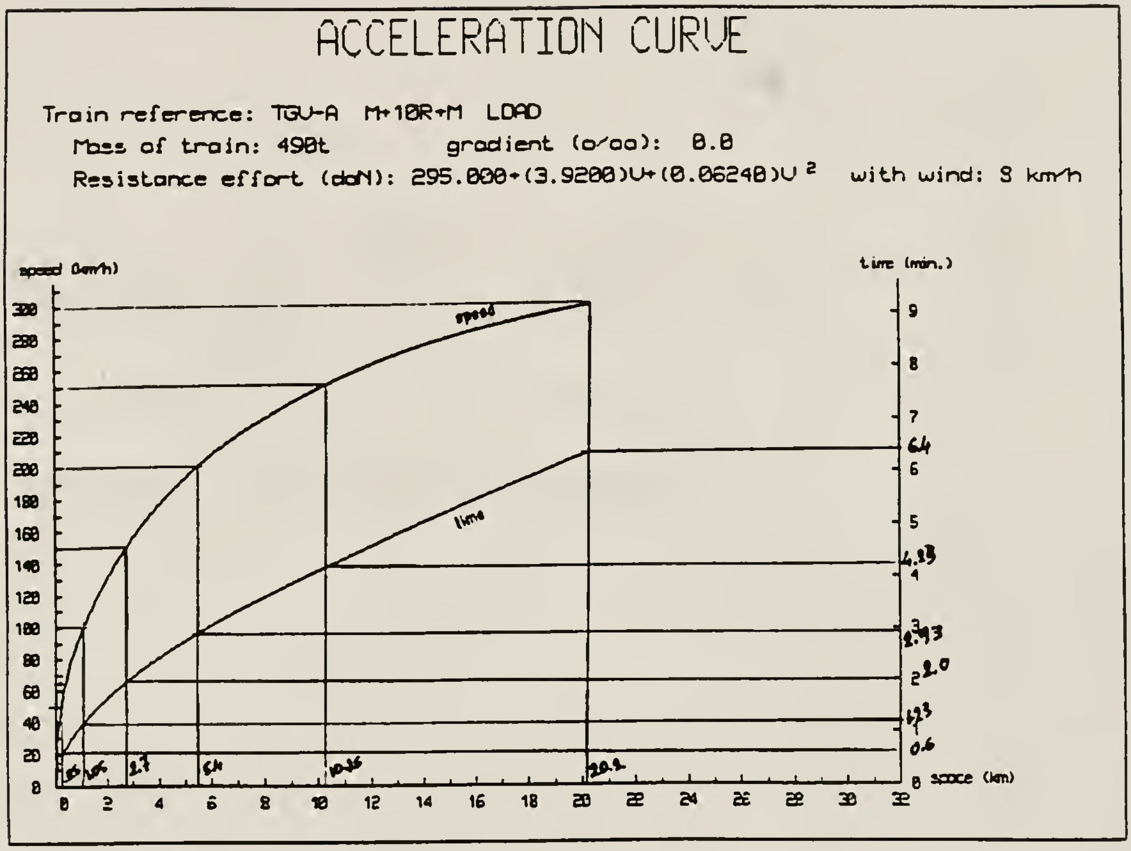
Where: a, $V_1$ and $V_2$ as previously defined

$t_1$ and $t_2$ are initial and final time (sec)

The distance and time measurements taken from the TGV-A speed profiles are illustrated in Figure 6-8. These measurements were used to compute the system's acceleration rates with a spreadsheet program based on the above equations.

Comfortable Deceleration Rates

As described in Chapter 2, most HSR trains use three different braking systems: regenerative dynamic, magnetic (eddy current), and disk brake systems. The disk brakes are usually reserved to emergency situations because they involve friction and cause wear. HSR and maglev trains are capable of a maximum deceleration rate varying from 1.2 $m/s^2$ to 1.5 $m/s^2$.



TGV-A Trainset
Computation of Acceleration Rates from Speed Profile

| Speed (km/h) | Measured Distance (km) | Measured Time (min) | Acceleration Based on Distance Inc. (m/s2) | Acceleration Based on Time Inc. (m/s2) | Speed Range (km/h) |
|---|---|---|---|---|---|
| 0 | 0 | 0 | | | |
| 50 | 0.25 | 0.60 | 0.386 | 0.386 | 0-50 |
| 100 | 1.05 | 1.23 | 0.362 | 0.367 | 50-100 |
| 150 | 2.70 | 2.01 | 0.292 | 0.297 | 100-150 |
| 200 | 5.40 | 2.93 | 0.250 | 0.252 | 150-200 |
| 250 | 10.25 | 4.23 | 0.179 | 0.178 | 200-250 |
| 300 | 20.20 | 6.40 | 0.107 | 0.107 | 250-300 |

Figure 6-8: Computation of Acceleration Rates from Speed-Distance and Speed-Time Profiles

In normal operation, however, the comfortable deceleration rate varies between 0.4 $m/s^2$ and 0.8 $m/s^2$. For instance, a comfortable deceleration rate of 0.7 $m/s^2$ is recommended for Transrapid. The rates for HSR systems are slightly lower. The simulation model can accommodate either one uniform deceleration rate or variable deceleration rates per speed increments.

## Energy Consumption

Energy consumption increases with speed due to air resistance. For the HSR systems, only an average energy consumption rate per mile was provided. For the transrapid trainsets, the energy consumption rates was provided at four different speeds for various trainset sizes as shown in Appendix E. These data were plotted on a graph that is presented in Figure 6-9. Then a curve fitting method was used to approximate each curve with a quadratic equation. The equations proved to be an excellent fit and were used in the model to estimate Transrapid's energy consumption rates as a function of speed and number of sections per trainset. The resulting curve fitting equations are the following:

Transrapid 3 sections: $En = 7.55 - 0.0194\ V + 0.000100\ V^2$

Transrapid 5 sections: $En = 12.50 - 0.0315\ V + 0.000155\ V^2$

Transrapid 6 sections: $En = 15.17 - 0.0396\ V + 0.000187\ V^2$

Transrapid 8 sections: $En = 18.60 - 0.0392\ V + 0.000240\ V^2$

Where: $En$ = energy consumption rate (kWh/km)

$V$ = speed (km/h).

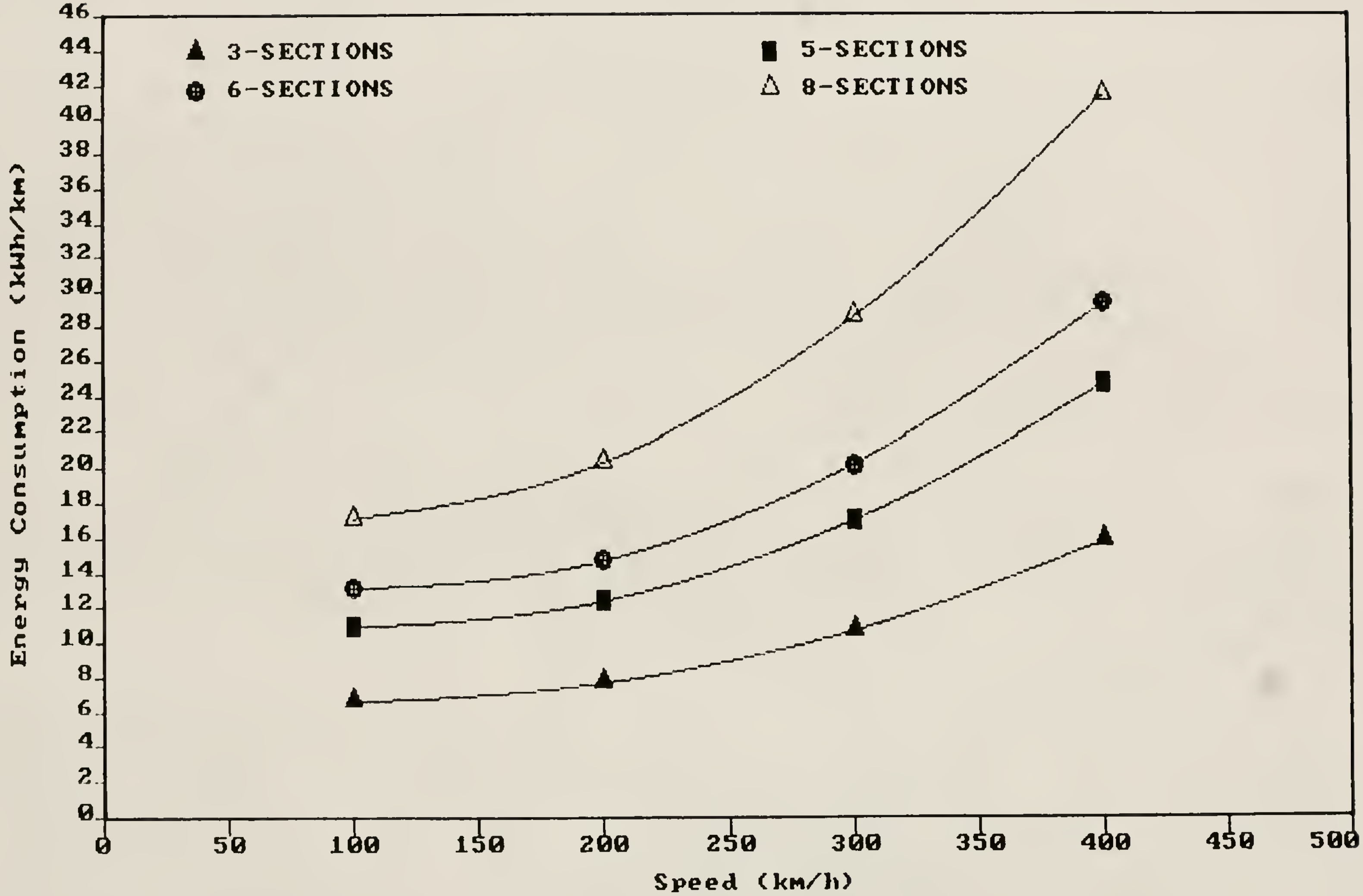


Figure 6-9: Transrapid Energy Consumption Rates vs. Speed for Four Trainsets

### Noise Emission

Noise emission measurements at five speeds were also provided for the Transrapid maglev train. These data were plotted and the curve was approximated with a quadratic equation that was used in the model. These measurements were recorded for elevated guideways. At near-grade guideways, Transrapid's noise levels are lower. Figure 6-10 illustrates the noise emission levels of various HSR and maglev systems.

### Comfort Limits

The FRA current regulations related to comfort-limit parameters are too restrictive for HSR and maglev operation because they were designed for freight trains and passenger trains not exceeding a speed of 175 km/h (110 mph) as explained in Chapter 5. Furthermore, track superelevation and lateral acceleration (i.e., unbalanced superelevation) are both measured in inches. This format is inappropriate for maglev systems because they do not use the standard track gauge. Superelevation should me measured in degrees and lateral acceleration in $m/s^2$ or as a percent of gravity (g).

The USDOT is currently reviewing the comfort limits for HSR and maglev systems. The review is not completed yet, however, a draft report was published in 1992 (USDOT, 1992). Table 6-1 is based on this draft report.

## Model Validation

The model was validated in four different ways: First, simulation outputs were checked to verify that the train

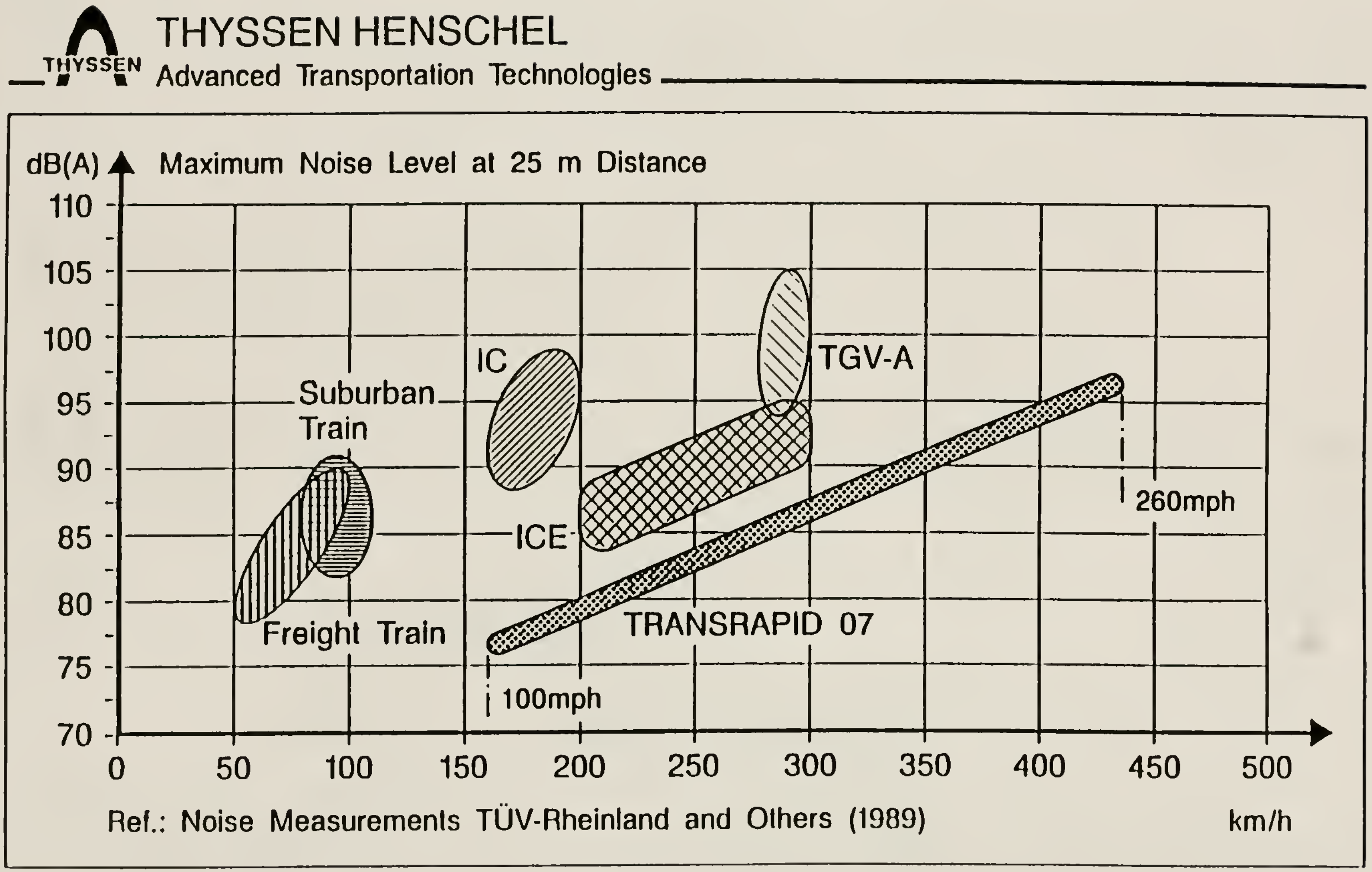


Figure 6-10: Noise Emission Levels of Various Transportation Systems
Source: Bechtel Corporation, 1990.

Table 6-1: Comfort Parameters for Various HSGT Technologies

| Parameters | TGV | Transrapid 07 | U.S Maglev |
|---|---|---|---|
| Maximum Speed (km/h) | 320 | 485 | 485 |
| Maximum Bank Angle or Track Superelevation (degrees) | 6 | 12 | 30 |
| Unbalanced Lateral Acceleration limit (g's) | 0.10 | 0.10 | 0.10 |
| Unbalanced Upward Acceleration limit (g's) | -0.05 | -0.05 | -0.25 |
| Unbalanced Downward Acceleration limit (g's) | 0.20 | 0.20 | 0.25 |
| Unbalanced longitudinal Acceleration limit (g's) | 0.16 | 0.16 | 0.16 |
| Unbalanced Longitudinal Deceleration limit (g's) | 0.075 | 0.15 | 0.16 |
| Maximum Grade (%) | 3.5 | 10 | 10 |
| Station Dwell Time (min) | 2 | 2 | 2 |

Note: $g=9.81\ m/s^2 = 32.2\ ft/s^2$

Source: USDOT, 1992 (p.106)

operation at each route section was set to the correct acceleration, deceleration, constant speed, or stop mode; and that the correct acceleration rate that corresponds to the section's initial speed was used at each time. Furthermore, the speed profiles from various runs were visually checked to verify that the train slowed down for curves and other speed restrictions and stopped properly at stations. The program performed flawlessly, in all the simulation runs, the train's allowable speed or the route's speed limits were never exceeded.

Second, parameters were calculated by hand for several sections to verify that the model's calculations are accurate. Furthermore, model's transitional acceleration rates and rate adjustment for grades were checked for correctness. Curve allowable speeds and the summary table generated by the program were also verified with calculations by hand.

Third, a spreadsheet program was developed to compute all the simulation parameters for a number of successive sections. The program results were in complete agreement with the outputs of the simulation model.

And finally, a feature was added to the simulation model that instructs the program to automatically produce a speed profile and a deceleration profile for the selected technology if a value of zero was entered as the route length. The program instruction is to accelerate the train to its maximum speed, operate at maximum speed for a short distance, and then decelerate the train until it stops. The speed-distance-time profiles thus generated by the model were compared to those provided by the HSGT manufacturers and found to be similar.

## Study Cases

### Description of Study Cases

The model was used to simulate the operation of one maglev and three HSR systems on the Orlando-Tampa corridor. The selected systems are the following:

1. Transrapid Maglev (1P -4T-1P / 500 passengers)
2. TGV-A (1P- 8T -1P / 317 passengers)
3. ICE (1P-14T -1P / 759 passengers)
4. X-2000 tilt train (1P- 6T / 474 passengers)

The route's alignment was obtained from FDOT's High-Speed Rail Office, and is included in Appendix C. This information was used to develop four route data files corresponding to the four study cases described below. The listing of the four route files that serve as input to the operational model are included at the end of Appendix C.

Case A is based on the speed restrictions computed by a consultant to FDOT and printed on the route data documents included in Appendix C.

Case B is based on route curvatures. The model computes for each horizontal curve the maximum allowable speed based on track superelevation (banking angle) and the lateral acceleration rate recommended in USDOT draft report (USDOT, 1992). In addition, an effective tilt angle of six degrees was considered for the X-2000. Florida's topography in general does not include significant grades nor vertical curves.

Case C is similar to Case B except that the train stops at a station in Lakeland, located about 60 km (37.5 mi) from Tampa. A dwell time of two minutes is assumed.

Case D further assumes an alignment improvement of 6 of the route's 43 curves. The selection of the six curves was based on an examination of the speed profiles generated by the previous simulation runs.

The speed profile, travel time, and average speed of each of the 16 simulations runs (4 systems x 4 cases) are presented in Figures 11 to 26. Figure 27 shows a superimposition of all the runs of Case D.

## Simulation Results

A summary of all the simulation results is presented in Table 6-2. The main findings are the following:

1. By comparing the runs in Case A, the advantage of the maglev system is limited. For instance, Transrapid is only about 10% faster than TGV. The imposed speed limits do not allow Transrapid to reach its maximum speed nor take advantage of its higher allowable speed on curves.
2. In Case B, the model computes the maximum allowable speed on curves. Because the new draft U.S. regulations allow 12% banking angle for Transrapid and only 6% for TGV, Transrapid's average speed was

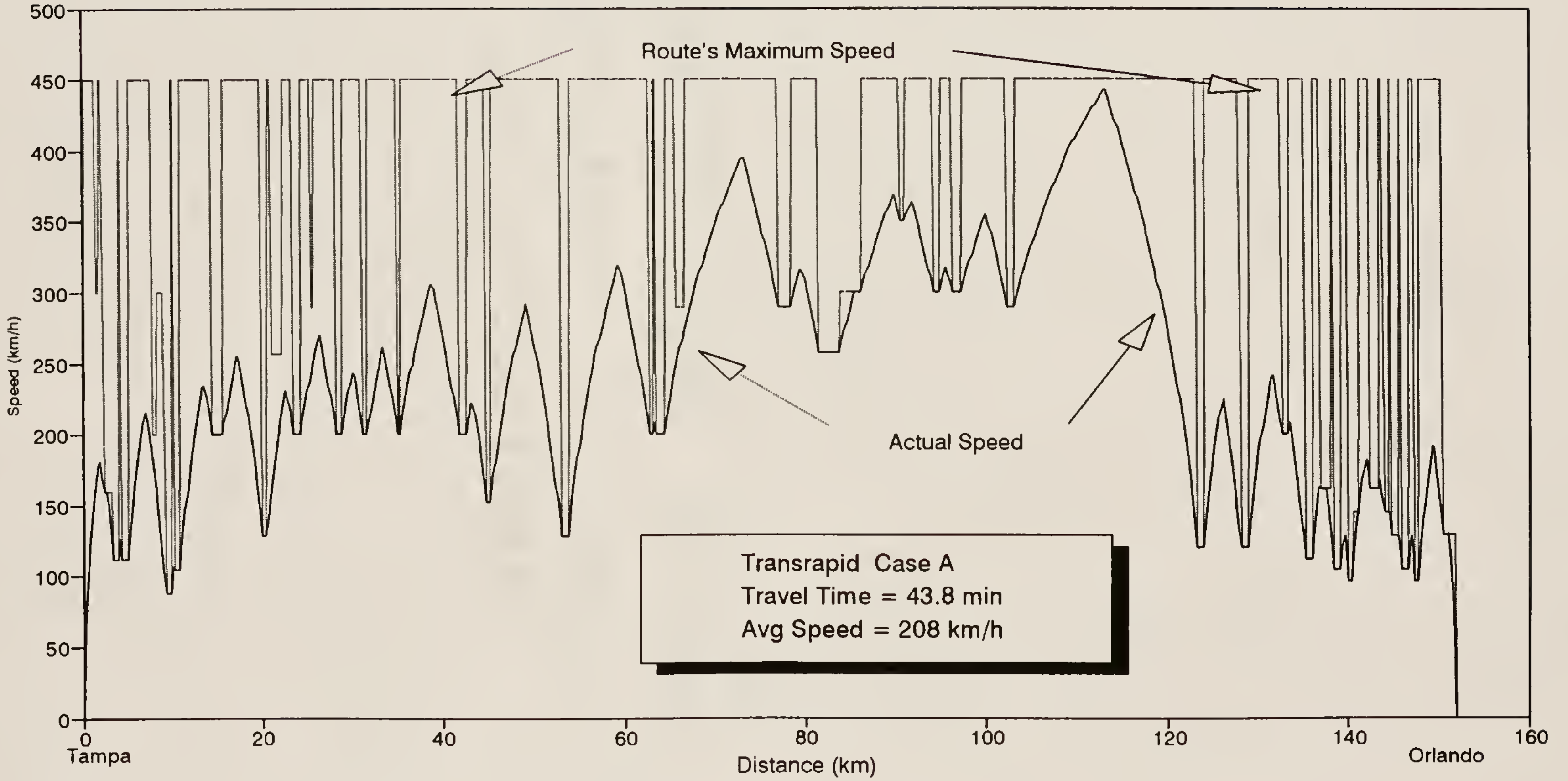


Figure 6-11:  Transrapid Run Case A

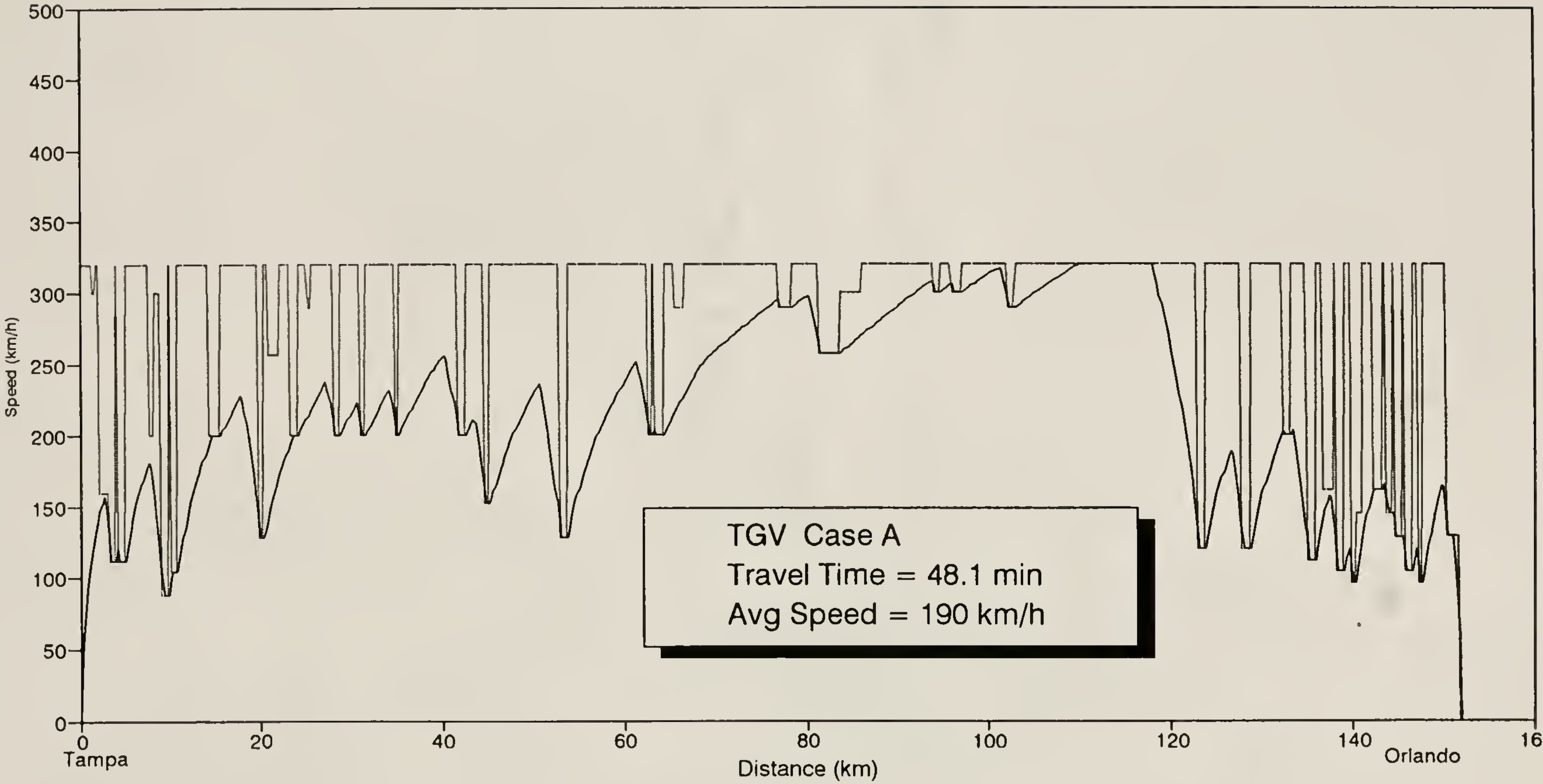


Figure 6-12: TGV Run Case A

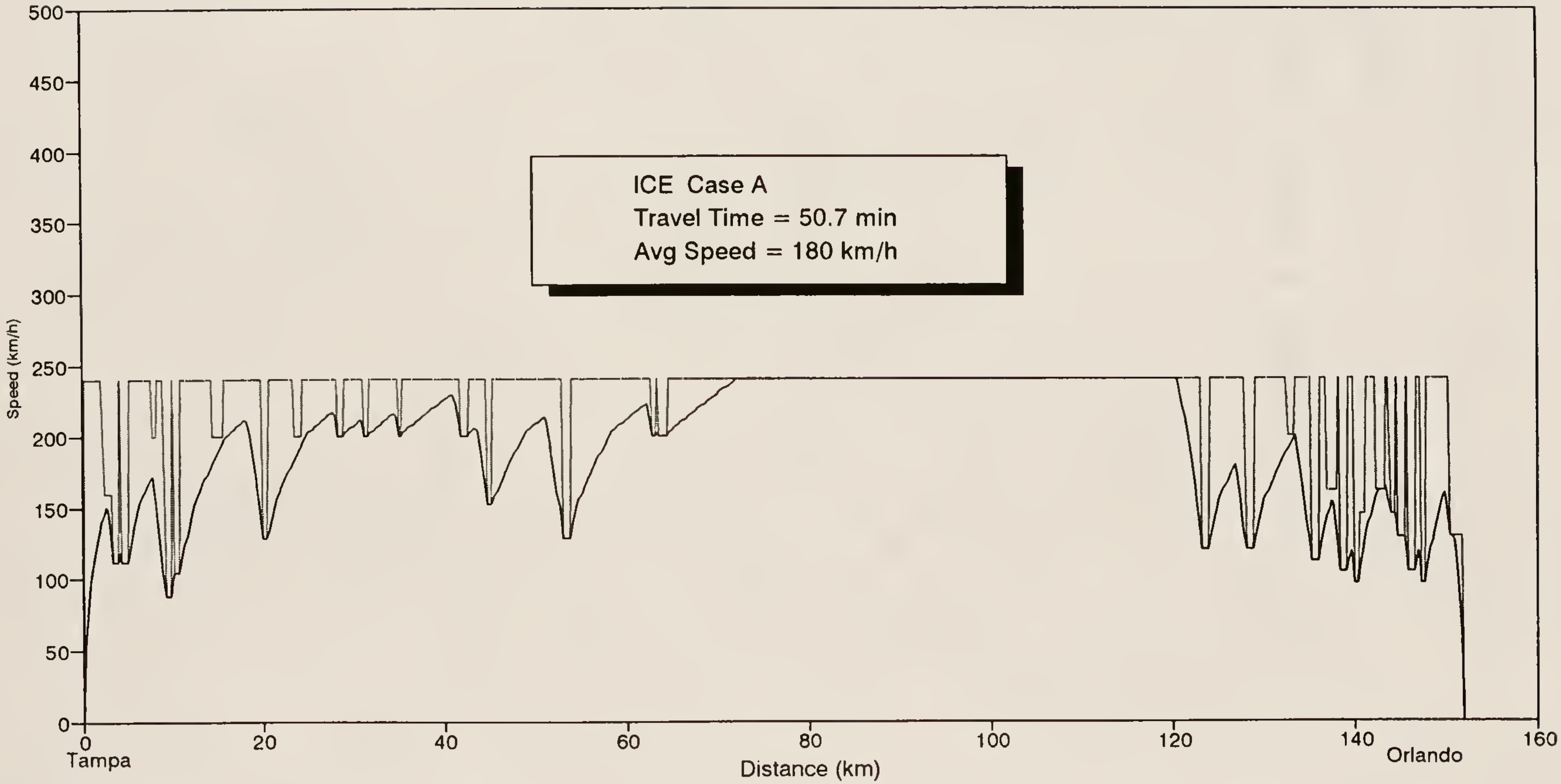


Figure 6-13: ICE Run Case A

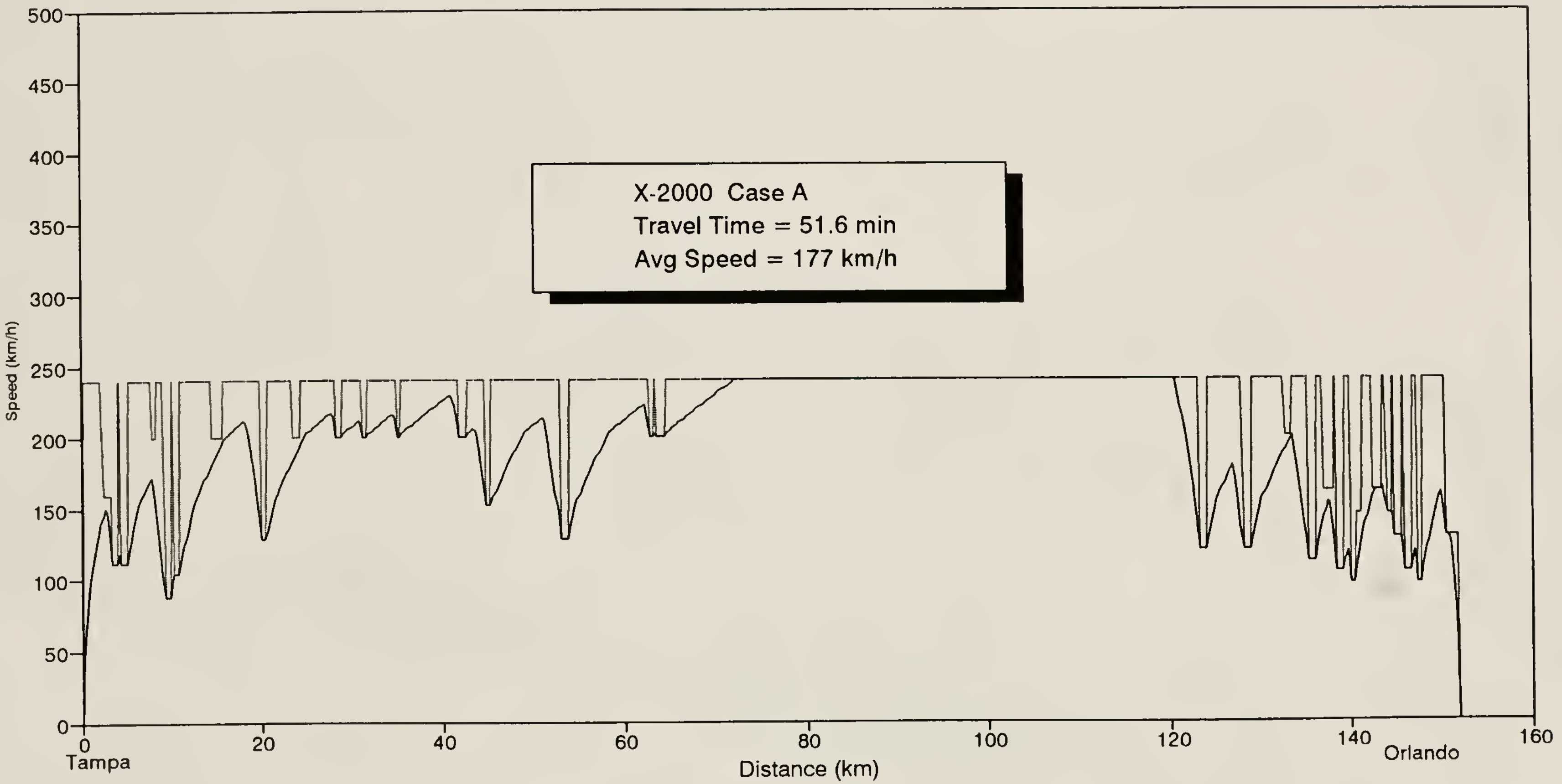


Figure 6-14: X-2000 Run Case A

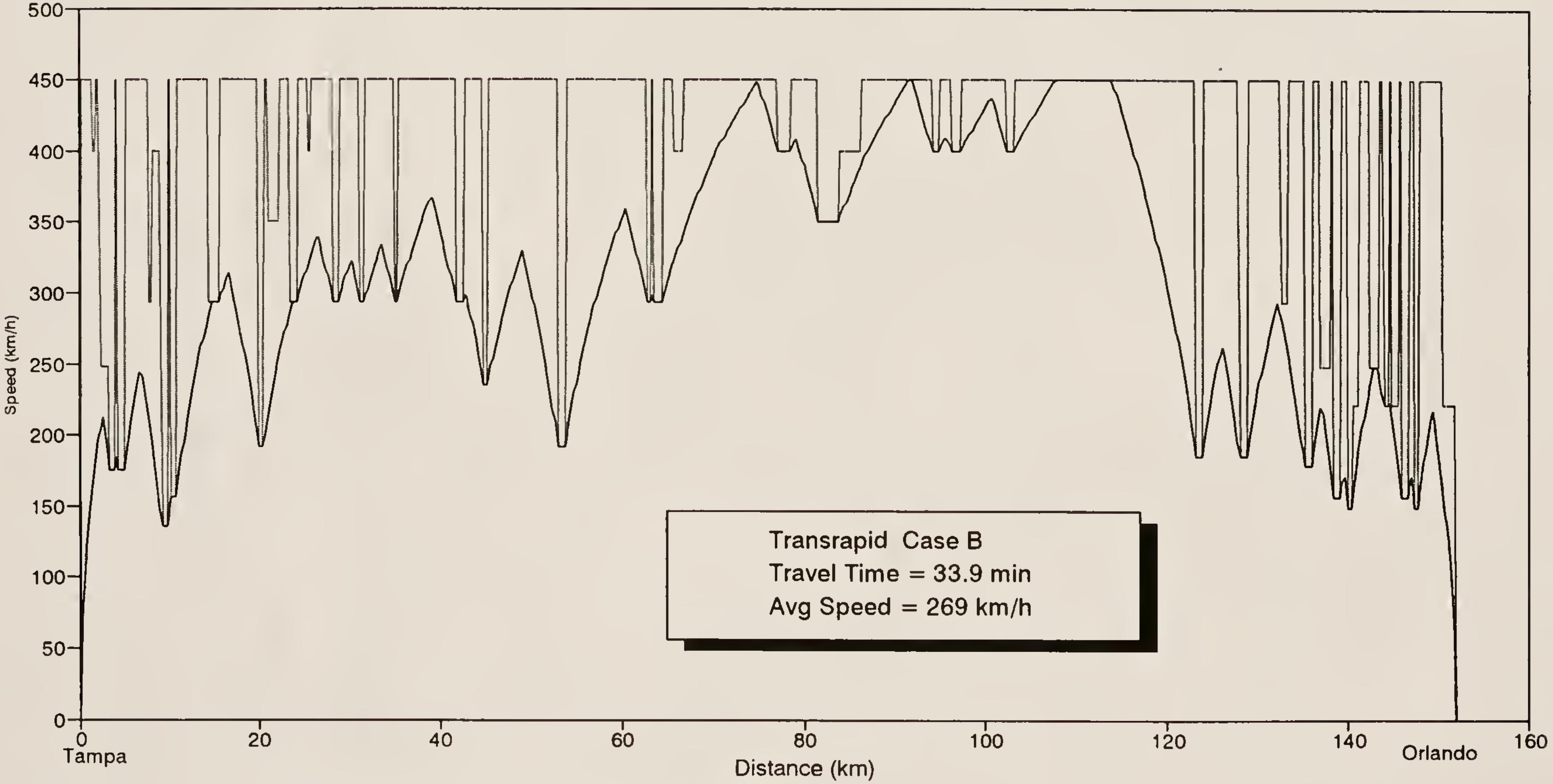


Figure 6-15: Transrapid Run Case B

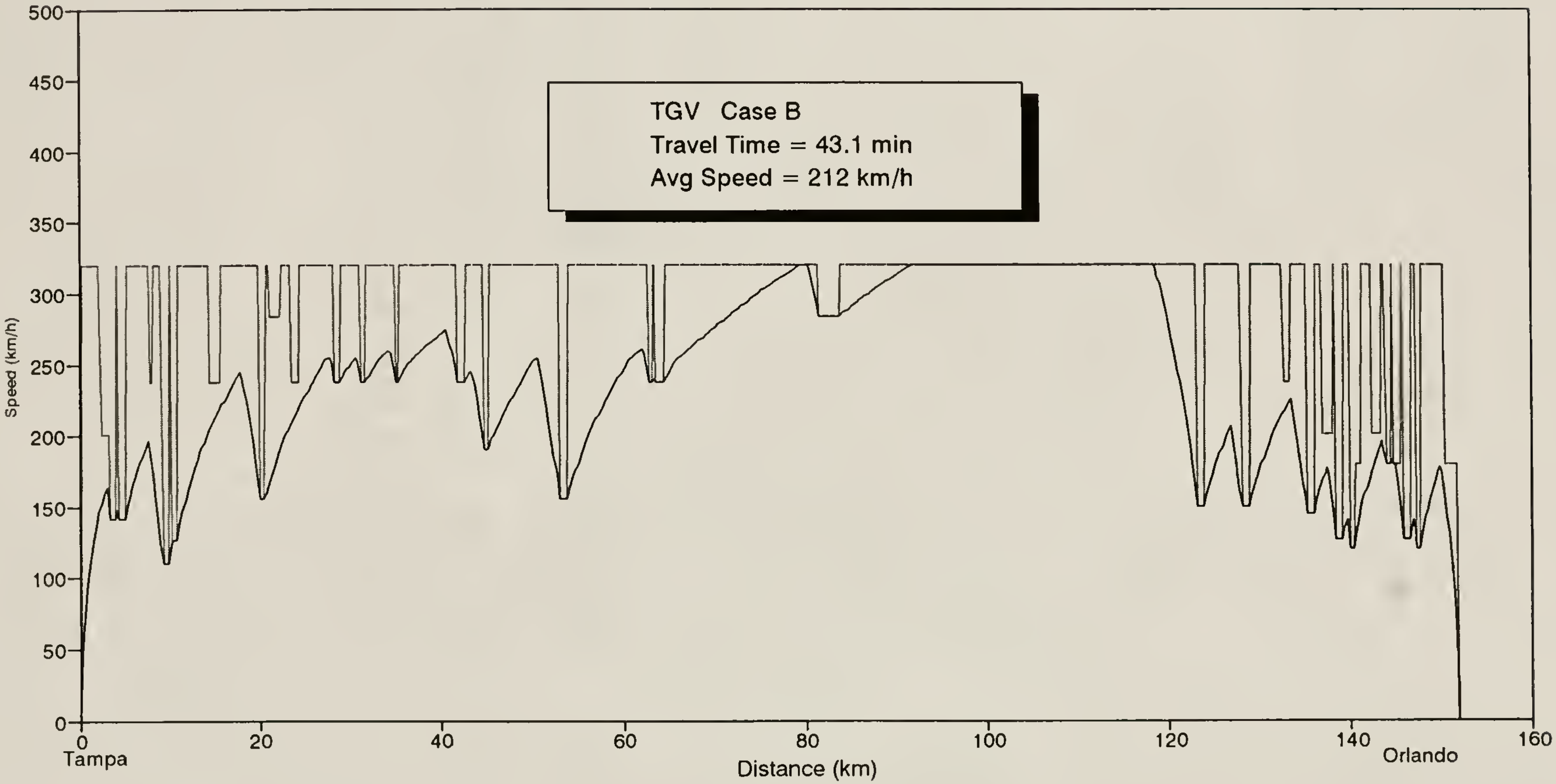


Figure 6-16: TGV Run Case B

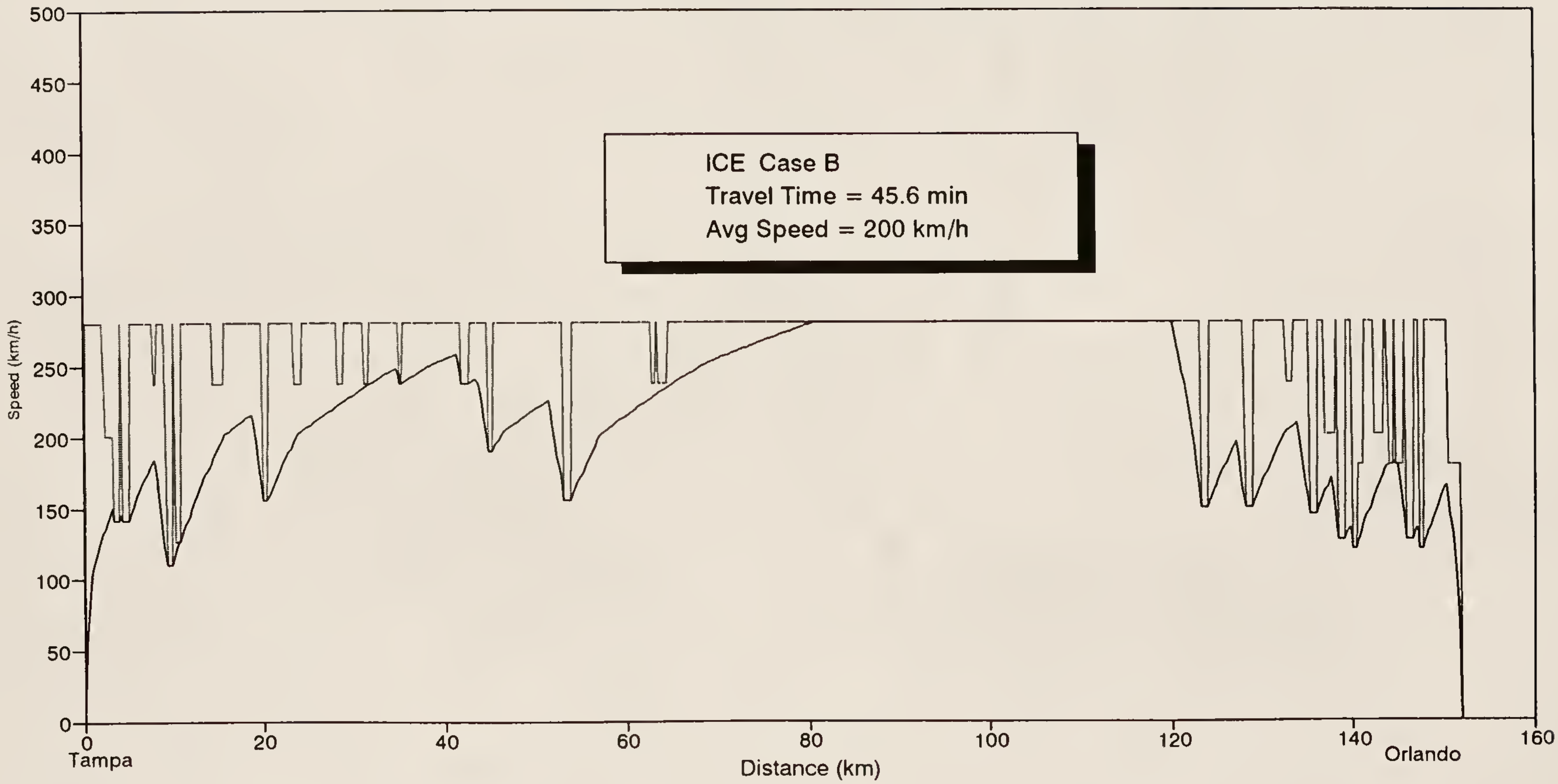


Figure 6-17: ICE Run Case B

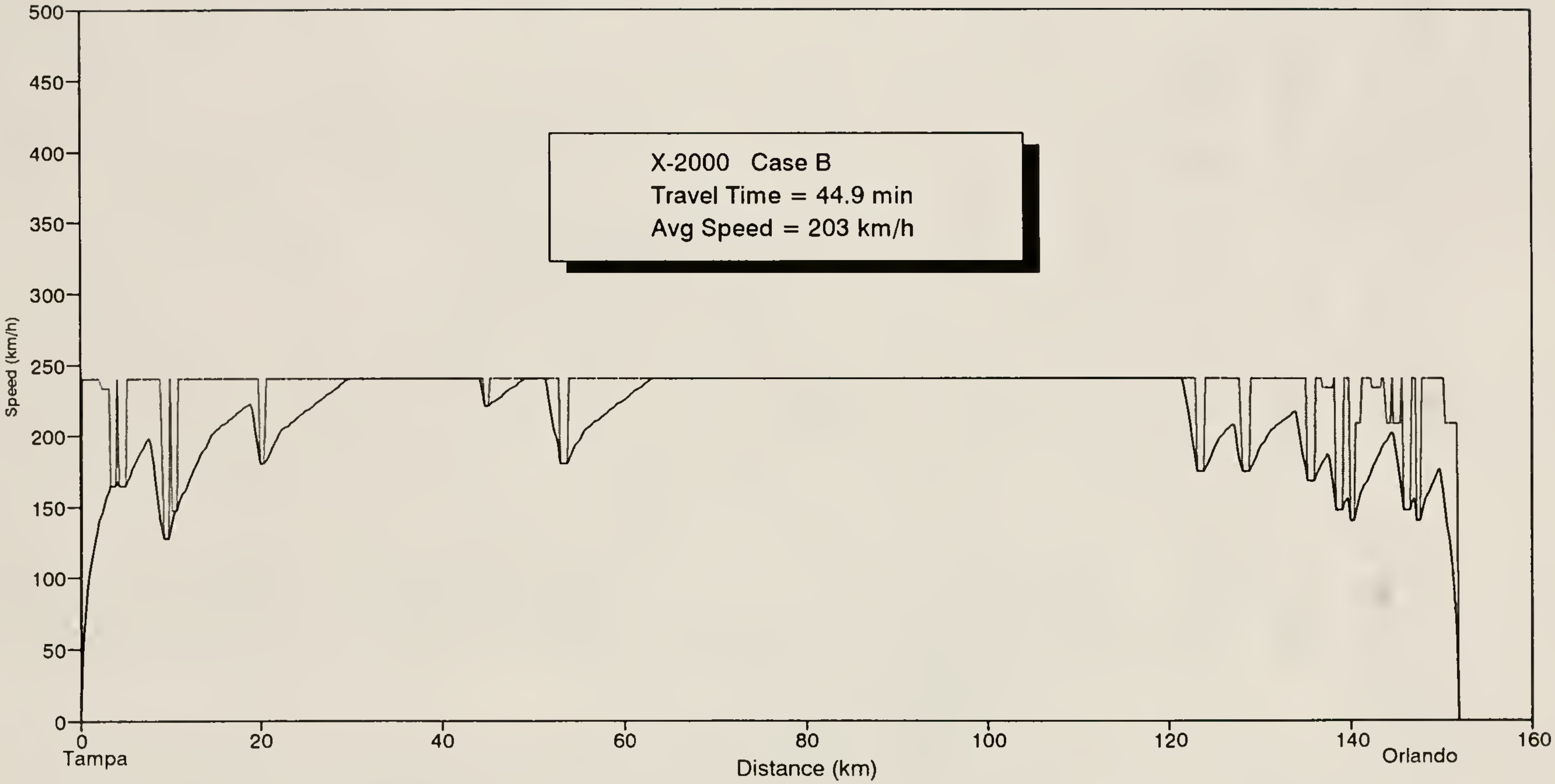


Figure 6-18: X-2000 Run Case B

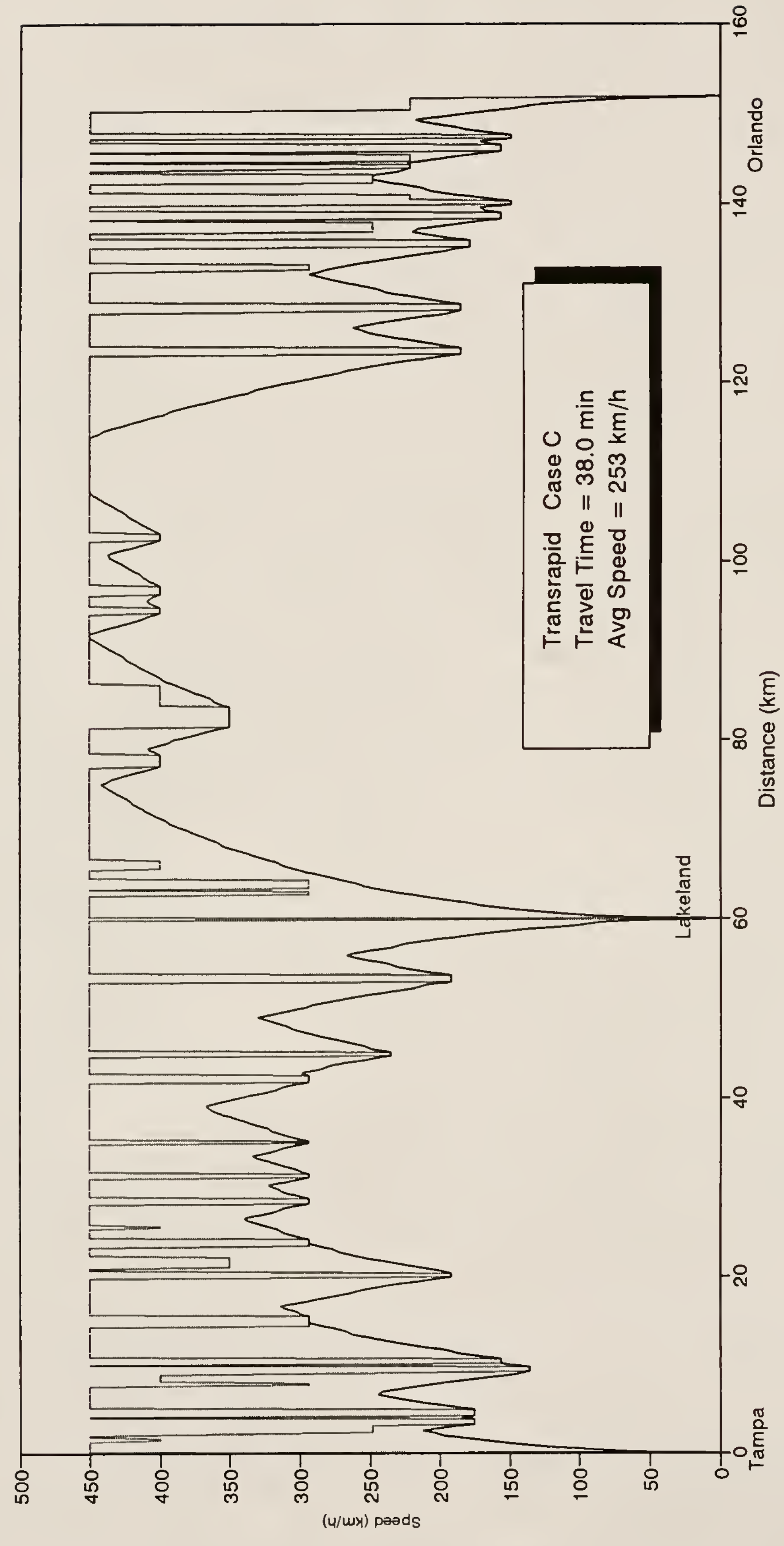


Figure 6-19: Transrapid Run Case C

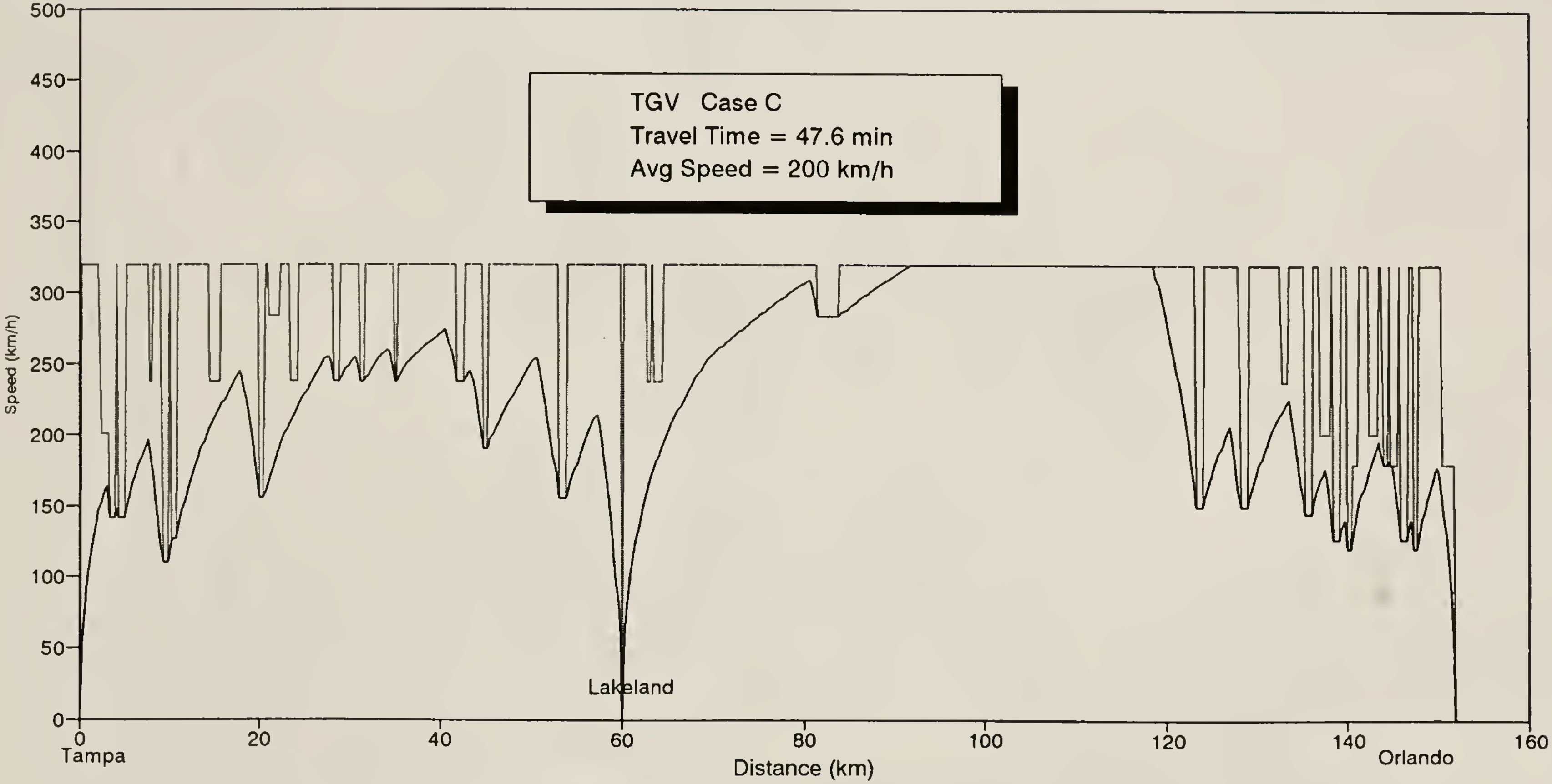


Figure 6-20: TGV Run Case C

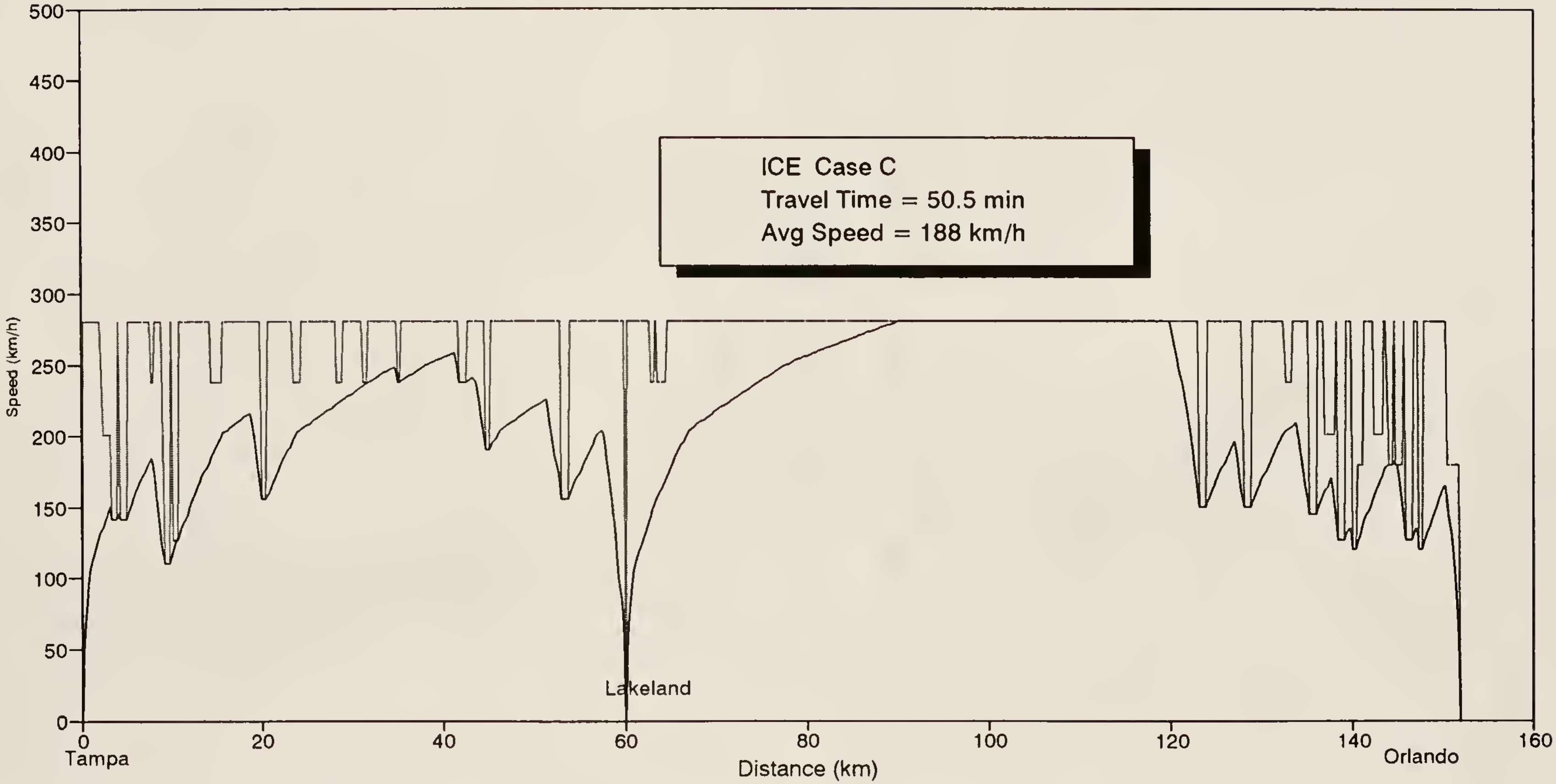


Figure 6-21: ICE Run Case C

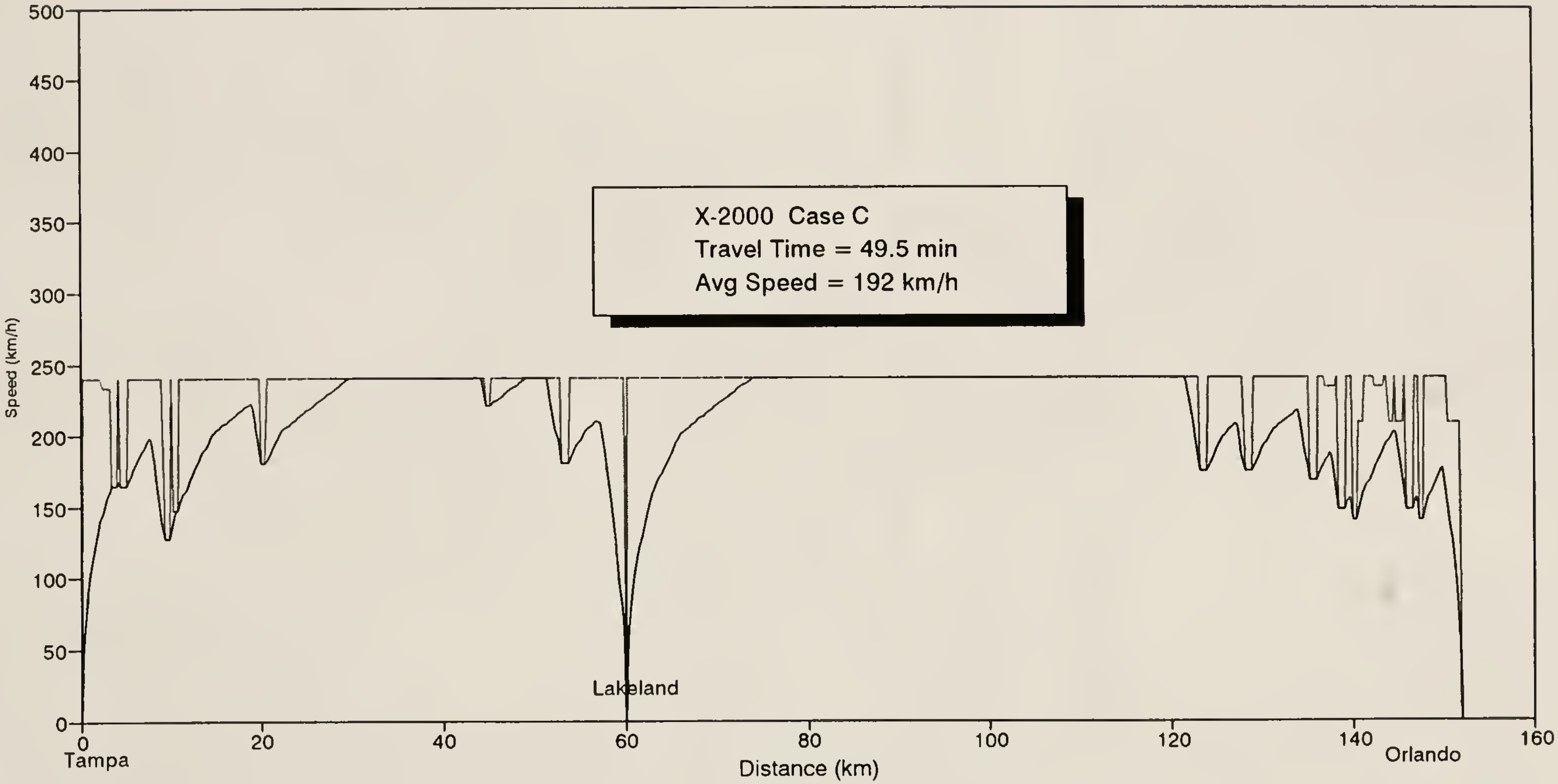


Figure 6-22: X-2000 Run Case C

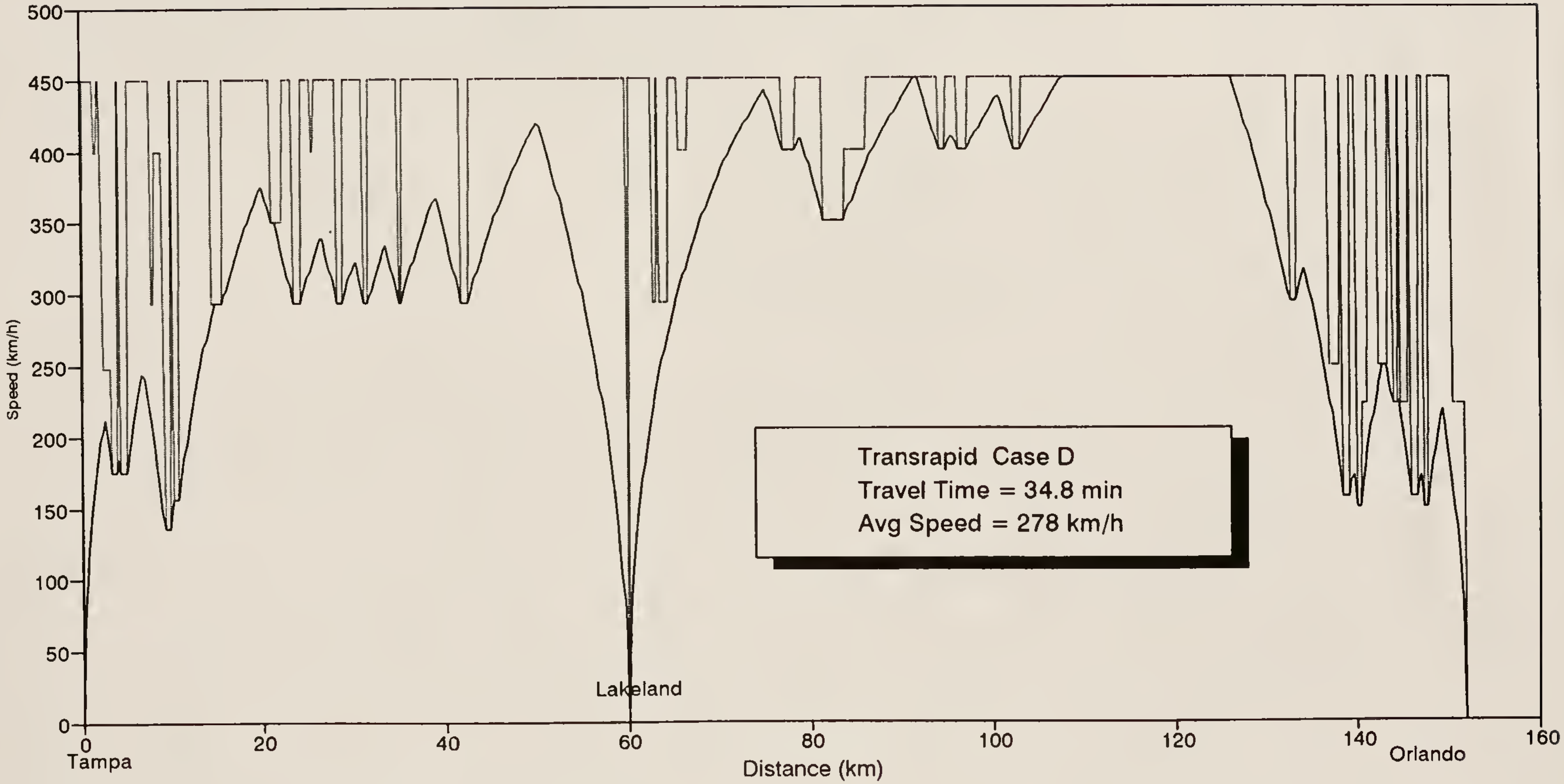


Figure 6-23: Transrapid Run Case D

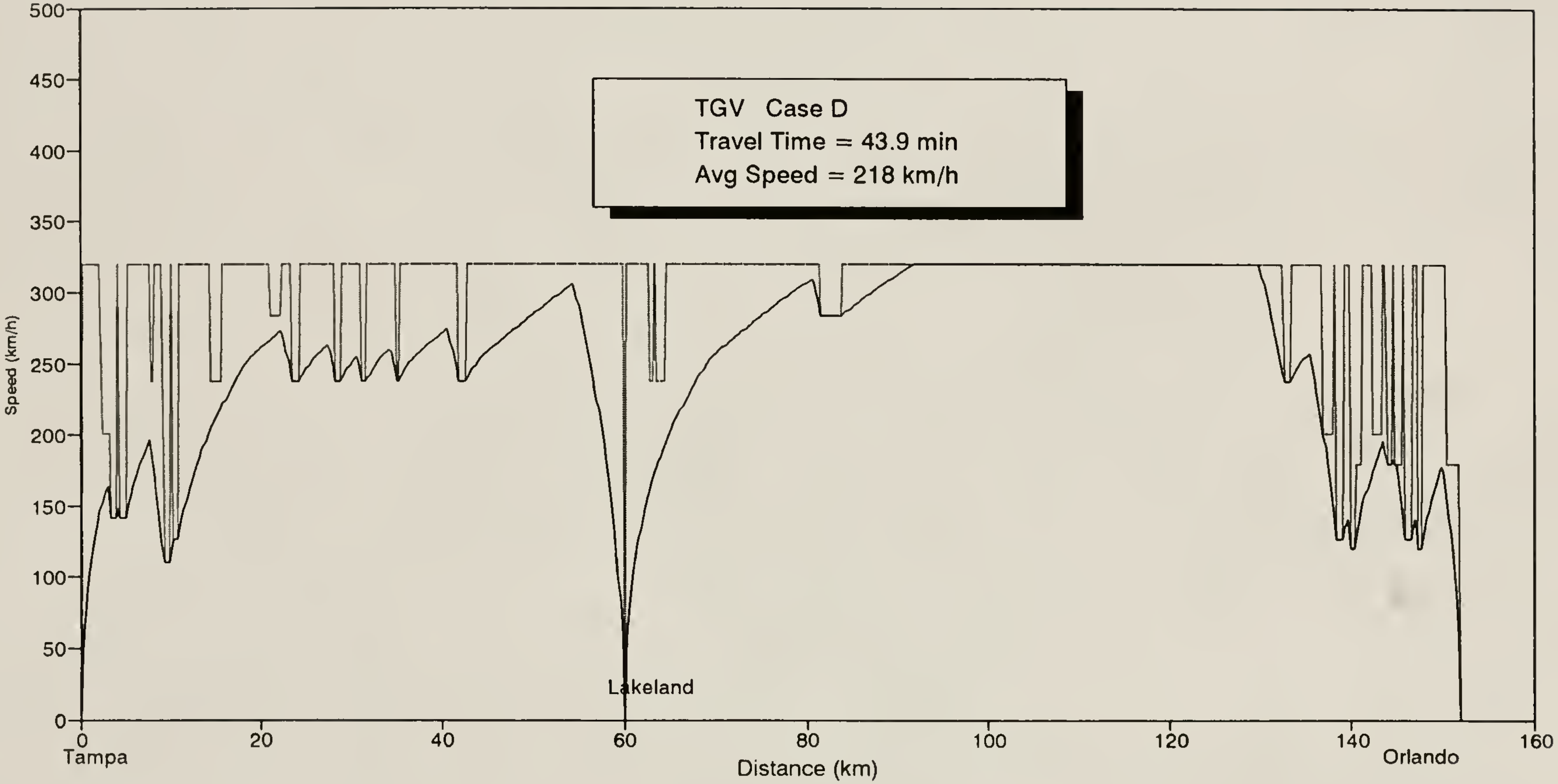


Figure 6-24:  TGV Run Case D

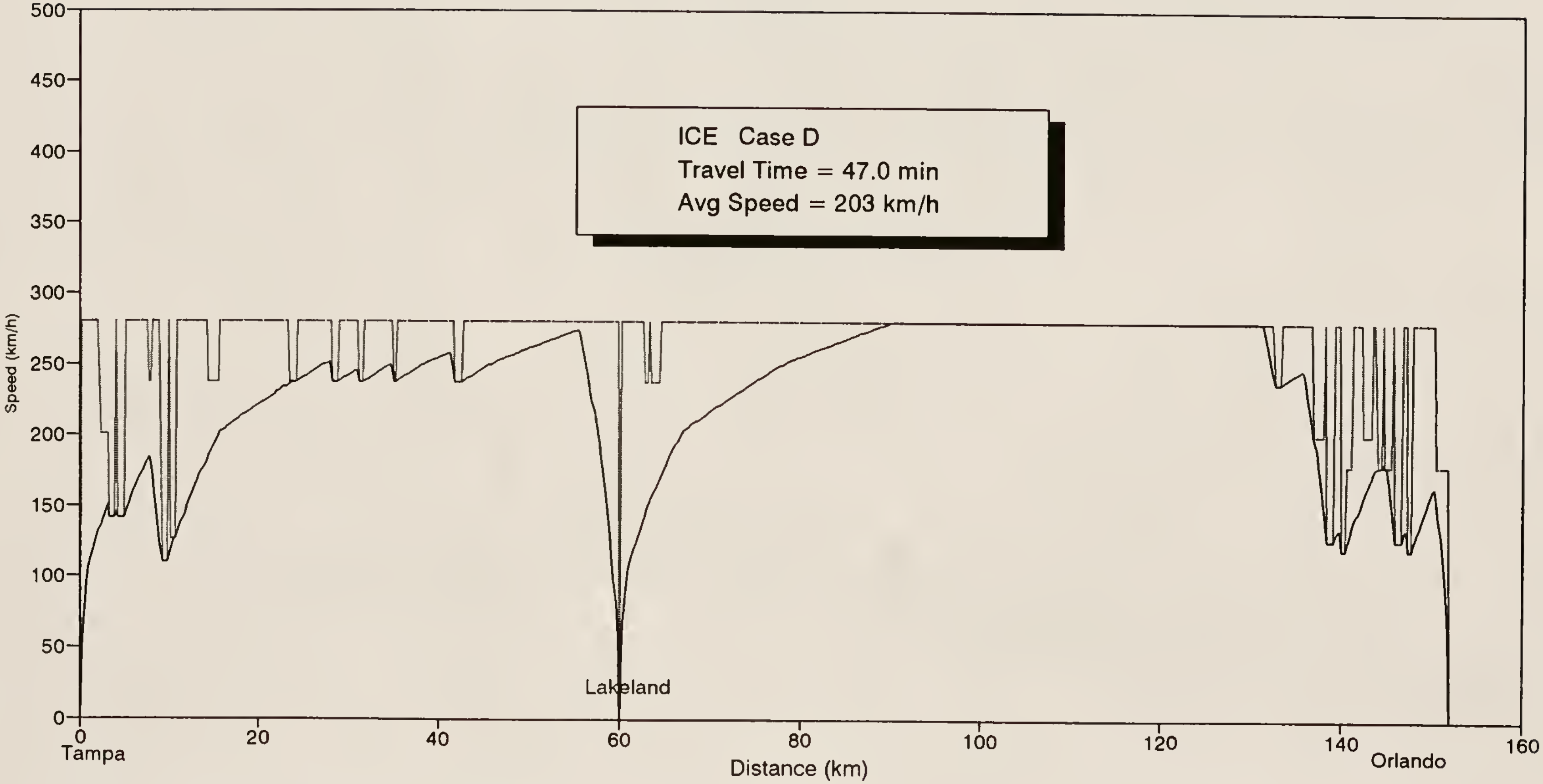


Figure 6-25: ICE Run Case D

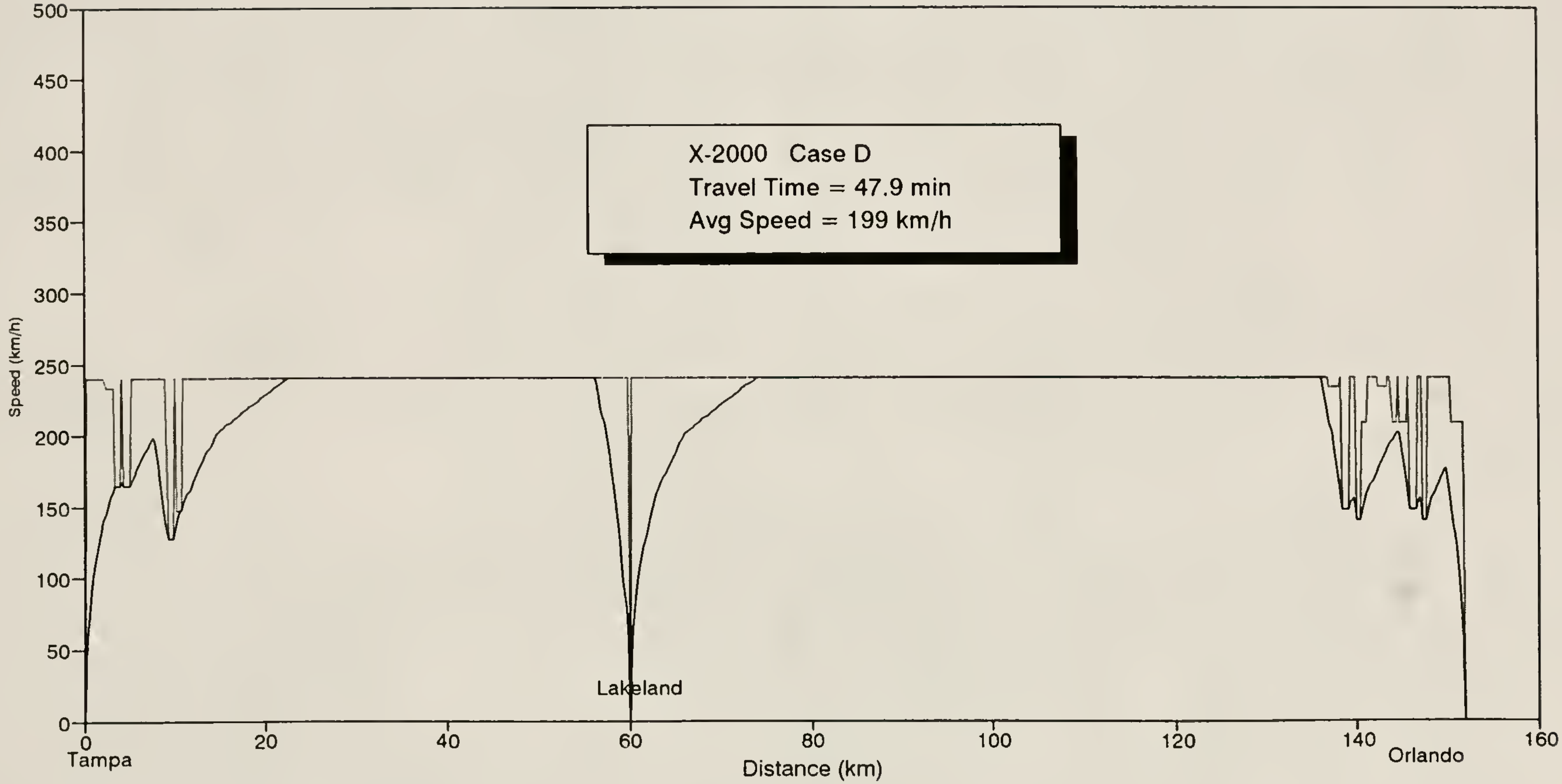


Figure 6-26: X-2000 Run Case D

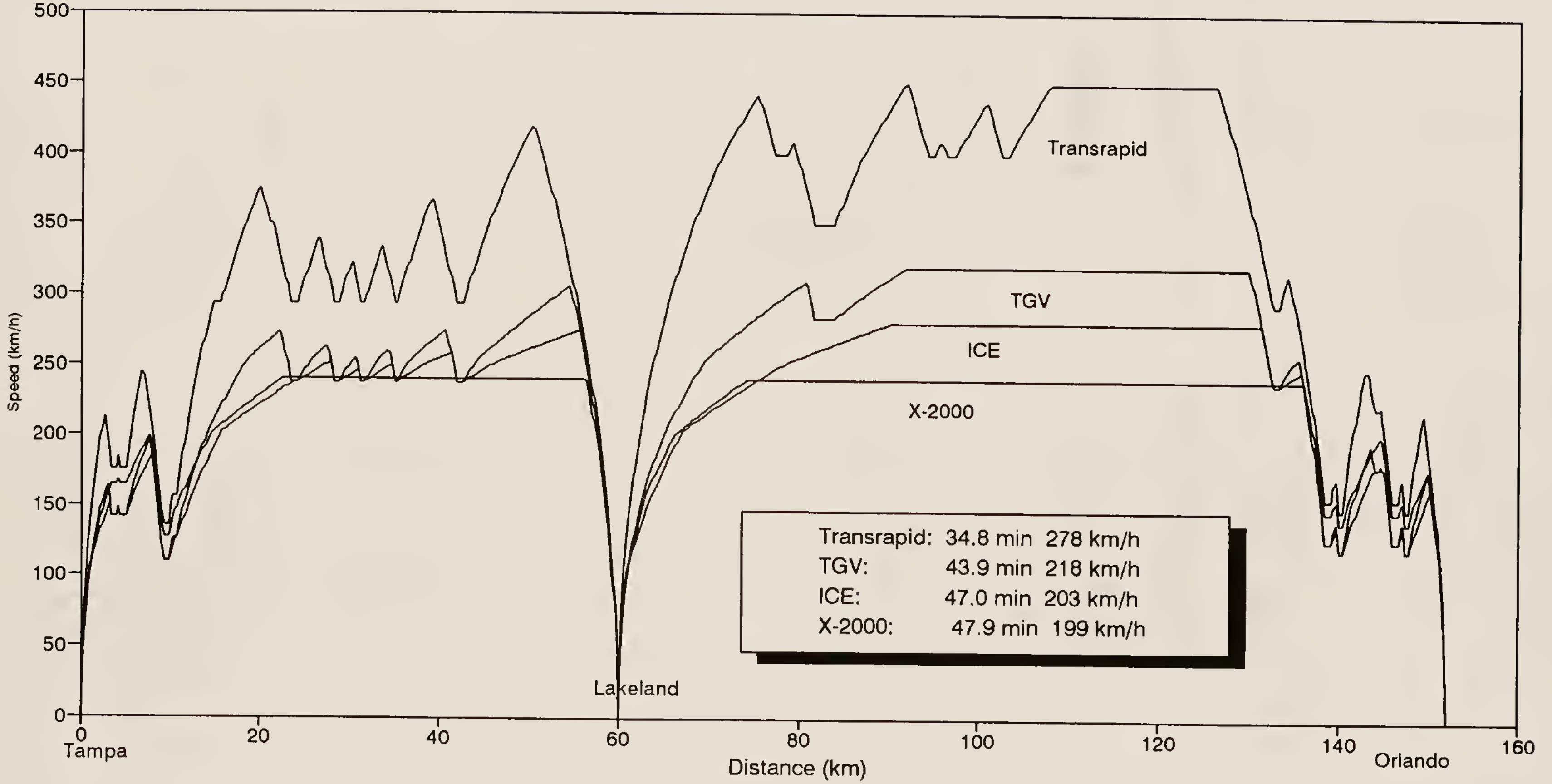


Figure 6-27: All System Runs Case D

Table 6-2: Simulation Results of Cases A Through D

| HSGT System | Case Study | Trip Time (minutes) | Avg Speed (km/h) |
|---|---|---|---|
| Transrapid 07 Maglev | Case A | 43.8 | 208 |
| French TGV | Case A | 48.1 | 190 |
| German ICE | Case A | 50.7 | 180 |
| Swedish ABB X-2000 | Case A | 51.6 | 177 |
| Transrapid 07 Maglev | Case B | 33.9 | 269 |
| French TGV | Case B | 43.1 | 212 |
| German ICE | Case B | 45.6 | 200 |
| Swedish ABB X-2000 | Case B | 44.9 | 203 |
| Transrapid 07 Maglev | Case C | 38.0 | 253 |
| French TGV | Case C | 47.6 | 200 |
| German ICE | Case C | 50.5 | 188 |
| Swedish ABB X-2000 | Case C | 49.5 | 192 |
| Transrapid 07 Maglev | Case D | 34.8 | 278 |
| French TGV | Case D | 43.9 | 218 |
| German ICE | Case D | 47.0 | 203 |
| Swedish ABB X-2000 | Case D | 47.9 | 199 |

increased by about 30% and TGV speed by only 12% as compared to case A. The average speed of the X-2000, although not as fast as the TGV, increased by 15% because of its tilt mechanism. While in Case A Transrapid was only 10% faster than TGV, it is 27% faster in Case B. This illustrates the importance of computing the allowable curve speeds separately for each technology.

3. Case C assumes one station at Lakeland and two minutes dwell time. This added four to five minutes to the trip time. Excluding dwell time, the extra time needed to decelerate to a stop at the station and accelerate again was as follows for each system: Transrapid: 2.1 min, TGV: 2.5 min, ICE: 2.9 min, and X-2000: 2.6 min.
4. Case D was similar to Case C except that six curves were smoothed out. This resulted in a 10% higher average speed for Transrapid, about 8% for both TGV and ICE, and only 4% for the X-2000. Transrapid benefited most because of its high acceleration rates. The X-2000 tilt train benefited least because it is less restricted by curves and its top speed is lower than that of the other systems.

## CHAPTER 7
## COST STRUCTURE OF HSR AND MAGLEV PROJECTS

The main capital and operational cost items of HSR and maglev projects are described in this chapter. The focus is on the French TGV, approved for implementation in Texas; and the German Transrapid, approved for a demonstration application in Orlando. Transrapid is the only very high-speed maglev certified as operationally ready. The Japanese MLU and the American maglev systems remain in the prototype design stage, and therefore their guideway's construction cost cannot be estimated. The Japanese HSST maglev system is operationally ready. However, it is not designed for very high speeds. It operates mainly as an urban people mover. A HSST system has been approved for implementation in Las Vegas.

Although the costs involved in an HSR project are illustrated using the TGV example, the basic construction differences between the French TGV and the German ICE, the Japanese Shinkansen, and the Swedish X-2000 are outlined. All these HSR systems have been successfully operating in revenue service. It is relevant to note that in constant money value, the actual construction costs of the TGV-SE line were less than one percent higher than the forecasted costs estimated seven years earlier (FF 8335 million vs. FF 8264 million--both figures are in 1989 FF) (Roth, 1990).

This chapter also includes a summary of the various HSR and maglev feasibility studies conducted in the United States. The cost information from these studies, although highly speculative, were used to develop a preliminary cost database that serves as input to the sample cost model presented in the next chapter. Whenever appropriate, Table 7-1 was used to translate cost data into a base year of January 1993. This table, however, is not valid for right-of-way costs which should be evaluated based on each state's real estate market.

## Capital Cost of HSR Systems

The total capital cost of an HSR system depends on the technology selected, the design speed, horizontal and vertical topography of the terrain, land purchase requirements, and the need for special structures and ancillary facilities. In general, the capital cost of an HSR system consists of the following components:

- Track and track bed.
- Earthwork.
- Electrification.
- Communication and signalization.
- Grade separation (rail and highway bridges).
- Special structures (tunnels, long bridges, elevated track, cut-and-cover structures, retaining walls, noise walls).

Table 7-1: Escalation Cost Factors to January 1993

| YEAR | INDEX BASE YEAR JAN. 1993 | YEARLY RATE OF CHANGE | INDEX BASE YEAR JAN. 1975 | ESCALATION FACTORS TO JAN. 1993 |
|---|---|---|---|---|
| Jan 1993 | 100.00 | 0.000 | 230.04 | 1.000 |
| July 1992 | 98.90 | 1.112 | 227.51 | 1.011 |
| July 1991 | 96.30 | 2.700 | 221.53 | 1.038 |
| July 1990 | 93.80 | 2.665 | 215.78 | 1.066 |
| July 1989 | 91.70 | 2.290 | 210.95 | 1.091 |
| July 1988 | 89.40 | 2.573 | 205.66 | 1.119 |
| July 1987 | 87.20 | 2.523 | 200.60 | 1.147 |
| July 1986 | 83.80 | 4.057 | 192.78 | 1.193 |
| July 1985 | 82.20 | 1.946 | 189.10 | 1.217 |
| July 1984 | 81.50 | 0.859 | 187.49 | 1.227 |
| July 1983 | 79.70 | 2.258 | 183.35 | 1.255 |
| July 1982 | 75.70 | 5.284 | 174.14 | 1.321 |
| July 1981 | 69.60 | 8.764 | 160.11 | 1.437 |
| July 1980 | 62.60 | 11.182 | 144.01 | 1.597 |
| July 1979 | 57.50 | 8.870 | 132.28 | 1.739 |
| July 1978 | 53.20 | 8.083 | 122.38 | 1.880 |
| July 1977 | 49.20 | 8.130 | 113.18 | 2.033 |
| July 1976 | 46.60 | 5.579 | 107.20 | 2.146 |
| July 1975 | 44.60 | 4.484 | 102.60 | 2.242 |
| Jan 1975 | 43.47 | 2.600 | 100.00 | 2.300 |

Source: Adapted from Means, 1993.

- Right-of-way.
- Stations.
- Maintenance facilities.
- Trains.
- Miscellaneous.

Table 7-2 provides the capital cost components of a proposal based on the X-2000 train submitted to Florida High-Speed Rail Commission.

Track

All HSR systems use continuous welded rail on concrete ties with elastic fasteners. The standard track gauge in North America and most of Europe is 1.42 m (56 in).

The track structure used by SNCF for its TGV lines consists of a minimum of 0.3 m (11 in) thick hard stone ballast layer (granite, traprock, or quartize ballast) with 25 mm to 50 mm (1 in to 2 in) square mesh grain size laid over an average depth of 0.2 m (8 in) subballast layer (RGCF, 1986). The subballast layer is made of crushed stone compacted to 100% optimum modified Proctor. Below the subballast is the subgrade which consists of either compacted native soil, or if the soil is unsuitable, compacted backfill material (TRB, 1991). Embankments are designed with a 3/2 slope, or 2/1 slope if they are made of fine soil (Chambron, 1986).

SNCF uses twin reinforced concrete cross ties at a center spacing of 0.6 m (23.6 in). The concrete ties are laid over the ballast to support the rails. TGV rails are made of heavy

UIC 60 kg/m (132 lb/yd) high-strength steel, manufactured with high surface quality and straightness. A manufacturing rail neutral temperature, that affects the thermal expansion, is established based on ambient temperature and daily temperature variations. The rail is welded in plants into 440 m (1,440 ft) strings. Rail strings are welded in the field. The track cross-section of the TGV system proposed for Texas and Florida is shown in Figure 7-1.

Nabla fasteners are used to provide lateral and longitudinal restraint. The rail is isolated from ties with elastomeric pads designed to reduce noise and tie wear (USDOT, 1991c). A typical cross-section of ties, fasteners and ballast of a TGV lines is shown in Figure 7-2. The track bed must provide good stability at very high speeds. To design a long-lasting track bed in Florida, special attention must be given to the type of soils, their water content, and the depth of the water table in order to insure an appropriate compaction of the subgrade or the embankments (Florida TGV, 1988). In urban areas, vibration can be reduced by using a 2 cm to 3 cm (about 1 in) layer of rubber under the ballast (Roth, 1990). Noise is reduced by building a concrete noise-abatement wall or an anti-noise embankment. A cut-and-cover design can also be used to reduce noise (Chambron, 1986) as illustrated in Figure 7-3.

The Japanese Shinkansen lines use extensively concrete slabs and special structures to support the track. Concrete

Table 7-2: Capital Cost of the FHSRC Proposal Submitted to the State of Florida based on X-2000 Train

| CATEGORY (Route= 323 miles) | TOTAL (1990$) | PERCENT (%) | PER MILE (1990$) |
|---|---|---|---|
| ELECTRIFICATION | $202,823,000 | 5.66% | $628,000 |
| SIGNALIZATION | $203,065,000 | 5.67% | $629,000 |
| ROADWAY BRIDGES | $173,072,000 | 4.83% | $536,000 |
| RAILROAD BRIDGES | $494,889,000 | 13.80% | $1,533,000 |
| RAILROAD EARTHWORK | $332,135,000 | 9.26% | $1,029,000 |
| TRACK | $234,840,000 | 6.55% | $727,000 |
| RIGHT OF WAY | $220,856,000 | 6.16% | $684,000 |
| UTILITY RELOCATION | $53,272,000 | 1.49% | $165,000 |
| MISCELLANEOUS | $253,893,000 | 7.08% | $786,000 |
| STATIONS | $100,583,000 | 2.81% | $312,000 |
| FEES | $440,557,000 | 12.29% | $1,365,000 |
| DESIGN CONTINGENCY | $567,357,000 | 15.83% | $1,757,000 |
| SYSTEM CONTINGENCY | $306,660,000 | 8.56% | $950,000 |
| TOTAL | $3,584,000,000 | 100.0% | $8,135,000 |

Source: FHSRC, 1990.

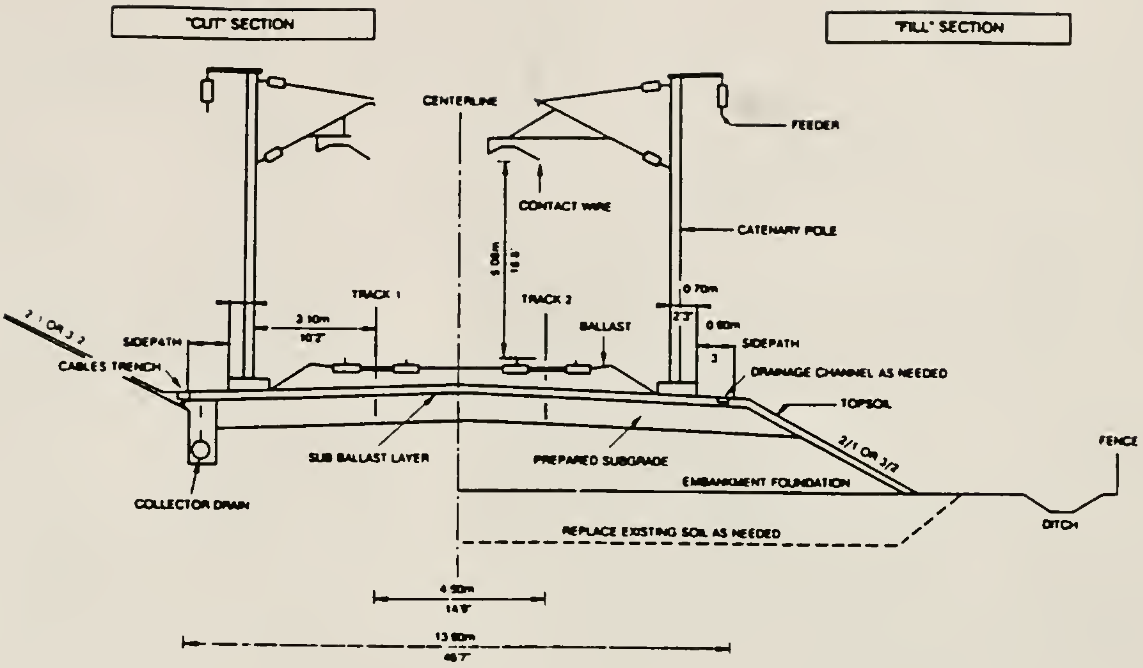


Figure 7-1: Cross Section of TGV Track
Source: USDOT, 1991c

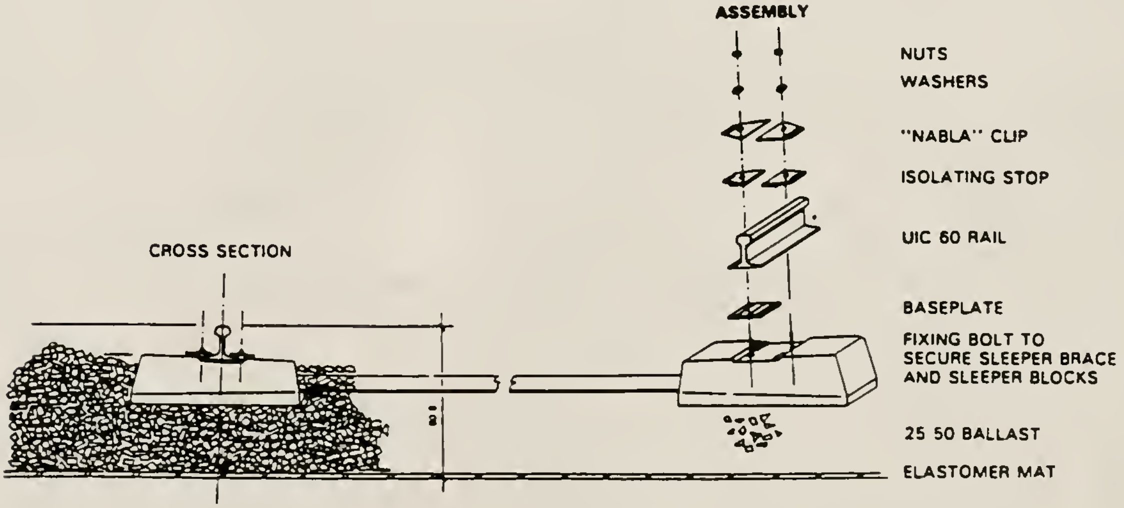
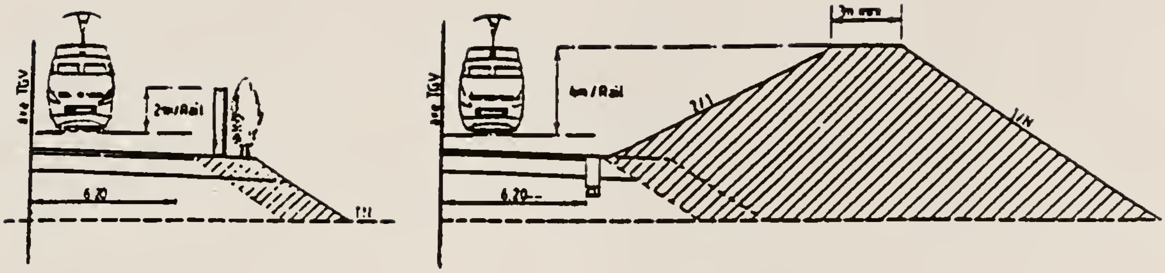
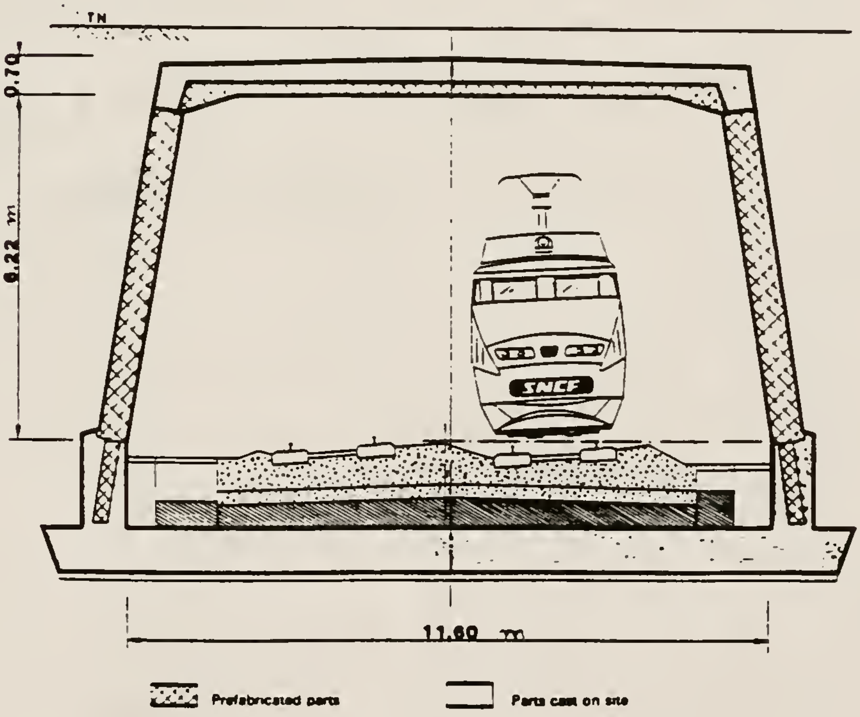


Figure 7-2: TGV Fasteners and Concrete Block
Source: USDOT, 1991c.



TGV Noise-Abatement Wall and Embankment



TGV Cut-and-Cover Structure

Figure 7-3: Embankments and Structures to Reduce TGV Noise
Source: Roth, 1990; Chambron, 1986.

slabs provide greater stiffness. They are however more expensive and cause higher levels of noise. The proposed ICE system for Texas was based on a 14 cm (5.5 in) slab track design. Although a slab track costs more than a ballasted track, it was estimated that the cost of maintaining a slab tracks is 75% to 80% lower than the cost to maintain a ballasted track (Bordelon and Rozek, 1987). The ICE lines in Germany use primarily slab tracks because they are designed for mixed traffic with heavier freight trains, whereas the TGV lines are for exclusive high-speed passenger operations.

There is very little information in the United States on upgrading existing tracks for HSR operation. The Northeast corridor track was upgraded for higher speeds. However, the maximum operating speed is limited to 200 km/h (125 mph).

### Earthwork

The amount and complexity of the earthwork required depend primarily on the terrain, the soil type, and the maximum grade allowed. For instance, the earthwork needed for the TGV-SE line was minimum because the line extended over an almost leveled terrain with few curvatures. The TGV Atlantic line was more difficult and needed more soil excavation and filling work. In addition, clay and silt soil layers covered most of the line’s layout. Because clay and silt are vulnerable to water, they were replaced by about three million cubic meters of borrowed material. The Japanese Shinkansen and the German ICE lines were laid over difficult terrain and therefore required extensive and costly earth preparation work.

In the United States, the terrain for both Florida and Texas is relatively leveled and somewhat similar to the TGV-SE terrain. The Florida TGV proposal (1988) described the terrain preparation as consisting of the following tasks:

- Stripping 0.2 m (8 in) of soil the width of the embankment. Typical embankment is 1.5 m (5 ft) high.
- Removal of poor soil materials and replacement by properly drained and compacted soil.
- Railroad excavation using scrapers and push dozers with a maximum haul of 1,500 m (5,000 ft). Excavation for borrow material is done by using a 1.5-CY backhoe. Borrow is hauled using 12-CY dump trucks. Then it is spread and compacted by dozers, scrapers and compactors to 95% density.
- Marshy areas require a 1-m (40-in) deep excavation of spoil material. Spoil is hauled to dump sites. Replacement soil is borrowed from suitable pits.
- Providing drainage and stabilizing the soil when needed.
- Landscaping by spreading 10 cm to 15 cm (4 in to 6 in) of topsoil. Then seeds, lime and fertilizer are added to the soil.

The earthwork activity for the proposed Florida TGV route amounted to about 23% of the total capital cost including trainsets (fixed plant and rolling stock) or about 27% excluding trainsets (fixed plant only).

## Electrification

High speeds and high rates of acceleration are only possible with electric propulsion which necessitates electrification of the lines. Electric propulsion has the additional benefits of lack of emissions and relatively quiet operation.

The power supply voltage for HSR systems is not uniform throughout Europe. The TGV-SE line uses a direct current of 1.5 kV. The TGV Atlantic and North lines use an alternating current of 25 kV and 50 Hz, respectively. The German ICE lines are designed for an alternating current of 15 kV and a frequency of 16.67 Hz. The TGV system proposed for Florida had the same electrification characteristics than the TGV Atlantic line. The TGV system proposed for Texas uses a voltage of 50 kV which reduces the supplied current by half.

Line electrification consists of preferably high voltage transmission lines that draw current from existing utility systems, traction substations to convert the high voltage to the voltage required by the electric engines of the trainset, and an overhead catenary system that transmits the electric current to the trainset's pantograph as it slides along the wires. In some cases, it is more cost effective to replace the high voltage transmission with a transmission taken directly from nearby utility voltage distribution systems by utilizing autotransformers.

The cost components of the catenary system and the electric substations are illustrated in Tables 7-3 and 7-4 respectively. These tables were prepared by Wilbur Smith Associates for the FDOT in a study completed in 1993 (FDOT, 1993). Typically, the electrification of an HSR line is between 8% and 12% of the system's capital cost.

### Communication and Signalization

The operation of high-speed trains requires communication and signalization systems designed for high speeds. This insures automatic control and braking in case of emergencies. Federal regulations require that trains traveling at speeds in excess of 130 km/h (80 mph) be equipped with cab signaling and an automatic braking system. Automatic Bloc Signaling (ABS) is a method for maintaining a safe distance between trains to reduce allowable headways to a minimum of four minutes. The ABS consists of dividing the track into a series of segments or blocks. Each block is protected by a wayside signal that displays the action that the operator of the train is supposed to take. If the train exceeds a block's safe speed, brakes are automatically applied and the central control system is notified (Guilloux, 1991). This is illustrated in Figure 7-4.

The cost and complexity of the signaling system depend on whether the line is designed for uniform trainsets, modular HSR trains, or mixed traffic with freight trains.

Signalization and communication cost components include the cost of equipments needed for train identification, track protection, wayside line supervision, and data transmission systems. These costs account for about 5% to 10% of the system's capital cost. Table 7-5 presents a breakdown of the signal cost per mile of a single track for Florida. The signal cost for a double track line was estimated by the same study at $474,187 per km ($758,700 per mile.)

Grade Separation

The cost for grade separation includes the costs of all the road bridges and railroad overpasses needed to completely separate the rail line from highway traffic. These costs depend on the number of crossings; the type, length, and width of each road crossing; the train's axle loading; and whether existing road bridges should be replaced, extended or modified. The cost of grade separation also includes the cost of relocating roads and utility at crossings.

For preliminary feasibility studies, the location and number of crossings can be identified from the following sources:

- U.S.G.S topographic maps (1:24,000).
- Aerial photographs.
- Field Inspection.
- The Department of Transportation.
- Cities' highway records.
- The Army Corps of Engineers' maps.

Table 7-3: Electrification Cost Per Mile for Two Tracks of a High-Speed Rail System (1993 dollars)

| Item Description | Material Quantity | Material Unit Cost | Material Total Cost |
|---|---|---|---|
| Catenary Foundation | 50 | $3,500 | $175,000 |
| Catenary Poles | 50 | $4,000 | $200,000 |
| Catenary guy Assemblies | 6 | $1,500 | $9,000 |
| Aerial Ground Wire | 10560 | $2 | $21,120 |
| Signal Power Support | 50 | $125 | $6,250 |
| Disconnect Switches | 2 | $5,000 | $10,000 |
| Rail Return Bonds | 2 | $7,500 | $15,000 |
| Catenary Wire System | 10560 | $12 | $126,000 |
| Catenary Arm Support | 50 | $1,200 | $60,000 |
| Section Insulators | 2 | $5,000 | $10,000 |
| Balance Weight Assembly | 2 | $10,000 | $20,000 |
| Bonding and Grounding | 1 | $15,000 | $15,000 |
| Protective Barriers | 2 | $7,500 | $15,000 |
| Warning/Safety Signs | 1 | $4,000 | $4,000 |
| Miscellaneous | 1 | $10,000 | $10,000 |
| **Labor Description** | **Labor Quantity** | **Labor Unit Cost** | **Labor Total Cost** |
| Catenary Construction | 5000 | $24.00 | $120,000 |
| **Subtotals** | | | |
| Material Costs | | | $697,090 |
| Material Overhead (15%) | | | $104,564 |
| Labor Costs | | | $120,000 |
| Labor Overhead (110%) | | | $132,000 |
| Truck & Miscellaneous | | | $12,000 |
| Contingencies (15%) | | | $159,848 |
| **Total Cost per Mile** | | | $1,225,502 |

Source: FDOT, 1993

Table 7-4: Power Substation Cost Per Mile (1993 Dollars)

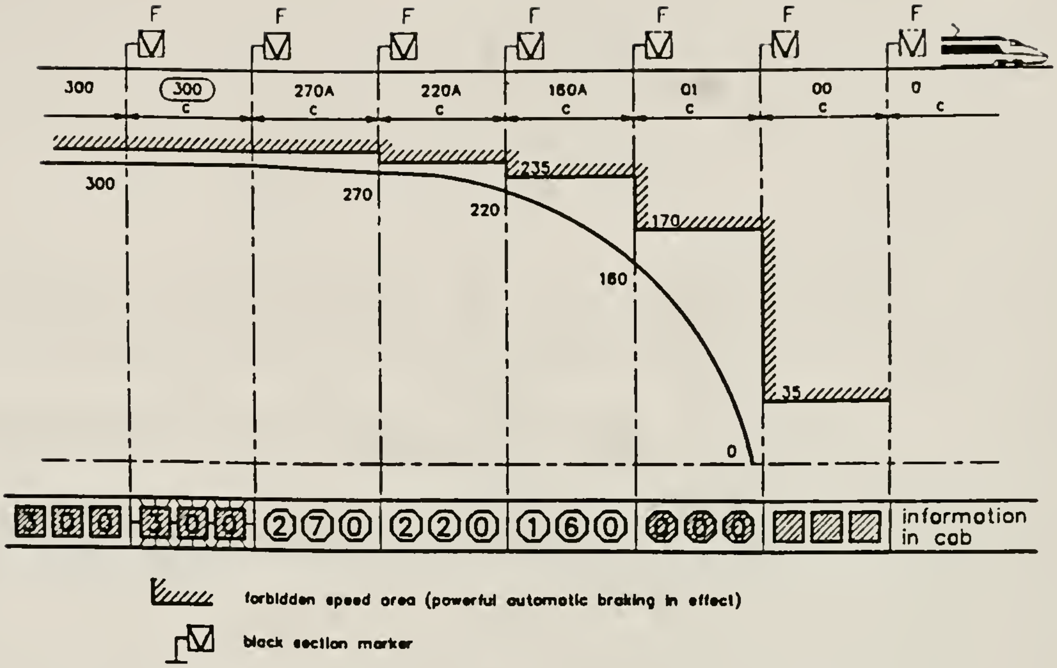
| **Item Description (1 Substation per 7 mi)** | **Material Quantity** | **Material Unit Cost** | **Material Total Cost** |
|---|---|---|---|
| Site work | 0.143 | $200,000 | $28,600 |
| Steel Structures | 0.143 | $650,000 | $92,950 |
| Buildings | 0.143 | $350,000 | $50,050 |
| High Voltage Dist-230KV | 0.143 | $250,000 | $35,750 |
| High Voltage Dist-6.9KV | 0.143 | $650,000 | $92,950 |
| High Voltage Dist- 25KV | 0.143 | $75,000 | $10,725 |
| High Voltage Dist-600KV | 0.143 | $50,000 | $7,150 |
| Control Equipment | 0.143 | $200,000 | $28,600 |
| Transformer-230KV/25KV | 0.286 | $400,000 | $114,400 |
| Circuit Breaker-230KV | 0.286 | $250,000 | $71,500 |
| Switchgear-25KV | 0.143 | $700,000 | $100,100 |
| Service & Distribution | 0.143 | $250,000 | $35,750 |
| Lighting and HVAC | 0.143 | $40,000 | $5,720 |
| Control Equipment | 0.143 | $200,000 | $28,600 |
| Miscellaneous | 0.143 | $15,000 | $2,145 |
| **Labor Description** | **Labor Quantity** | **Labor Unit Cost** | **Labor Total Cost** |
| Substation Construction | 1400 | $30.00 | $42,000 |
| **Subtotals** | | | |
| Material Costs | | | $704,990 |
| Material Overhead (15%) | | | $105,749 |
| Labor Costs | | | $42,000 |
| Labor Overhead (110%) | | | $46,200 |
| Truck & Miscellaneous | | | $1,200 |
| Contingencies (15%) | | | $135,021 |
| **Total Substation Cost per Mile (Spacing=7 mi)** | | | $1,035,160 |

Source: FDOT, 1993

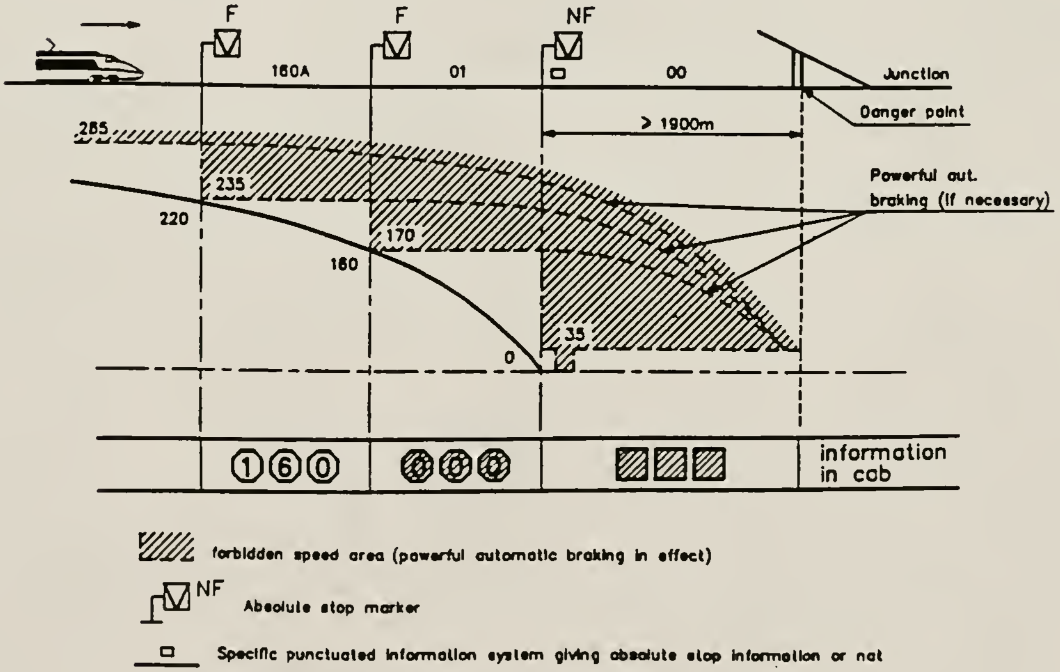
Table 7-5: Signaling Cost Per Mile Per Track (1993 dollars)

| **Item Description (Signal Spacing=30 mi)** | **Material Quantity** | **Material Unit Cost** | **Material Total Cost** |
|---|---|---|---|
| **Basic Signal Cost** | | | |
| Signal Interlocking | 0.033 | $200,000 | $6,600 |
| Electric Lock Complete | 0.033 | $5,000 | $165 |
| Switch Machine Powered | 0.033 | $20,000 | $660 |
| Train Identification | 1 | $30,000 | $30,000 |
| Impedance Bonds | 1 | $5,000 | $5,000 |
| Signal locations | 1 | $40,000 | $40,000 |
| Code Test Location | 0.033 | $35,750 | $1,179 |
| Communication & Control | 1 | $12,000 | $12,000 |
| Signal Miscellaneous | 1 | $10,000 | $10,000 |
| Cable (per mile) | 1 | $25,027 | $25,027 |
| Cab Signal Power | 0.033 | $973,334 | $32,120 |
| Signal Energy Source | 0.033 | $121,212 | $4,000 |
| Cab Signal Control | 0.033 | $206,061 | $6,800 |
| Control Center | 0.033 | $303,000 | $10,000 |
| **Labor Description** | **Labor Quantity** | **Labor Unit Cost** | **Labor Total Cost** |
| Signal Construction | 4300 | $30.00 | $129,000 |
| **Subtotals** | | | |
| Material Costs | | | $183,551 |
| Material Overhead (15%) | | | $27,533 |
| Labor Costs | | | $129,000 |
| Labor Overhead (110%) | | | $141,900 |
| Truck & Miscellaneous | | | $1,500 |
| Contingencies (15%) | | | $72,523 |
| **Total Signal Cost per Mile of Single Track** | | | $556,006 |

Source: FDOT, 1993



Stopping sequence for block sections.


F
F
NF
160A
01
00
Junction
Danger point
> 1900m
285
235
220
170
160
Powerful aut. braking (if necessary)
35
0
information in cab
forbidden speed area (powerful automatic braking in effect)
NF
Absolute stop marker
Specific punctuated information system giving absolute stop information or not

Principle of braking before an absolute stopping point.

Figure 7-4: TGV Track Block Sections and Automatic Braking
Source: Guilloux, 1991.

The Florida TGV proposal estimated the average cost per TGV bridge over highway at about $408,700; and roadway bridge over rail track at $352,500 (these costs are in 1988 dollars). Table 7-6 presents selected unit costs for roadway and railroad bridges for the X-2000 tilt train. Figure 7-5 shows the cross section of the ICE track and elevated structure, and a side view of a typical road bridge.

### Special Structures

Special structures refer to all structures other than the one needed for grade separation. This includes tunnels, long bridges (elevated structures) over wet areas or valleys, cut-and-cover, viaducts, retaining walls, and so on. The Florida TGV proposal estimated the cost for an elevated structure to be around $10.6 million per km ($17 million per mile), the cost of cut-and-cover structures was about $16.8 million per km ($27 million per mile), and the cost of a retaining wall was about $1.87 million per km ($3 million per mile)--all these cost estimates are in 1988 dollars. The cost of an elevated ICE guideway that includes electrification and signalization for the Texas corridor was estimated at $8.1 million per km ($12.8 million per mile) in 1986 dollars.

The TGV Atlantic line required 12.4 km (7.75 mi) of tunnels and 8.4 km (5.25 mi) of cut-and-cover structures. At Villejust, two single-track tunnels, each 4,800 m (3 mi) long, were excavated. A six-branch bored head excavator was used to dig a 9.25-m (30.3-ft) diameter tunnel. Pressurized bentonite slurry was used to stabilize the sides. This was followed by hydraulic mucking. Finally, a hydraulic erector was used to place precast reinforced concrete segments that were produced on-site in a highly automated plant capable of manufacturing 135 segments daily (about 28 m or 92 ft). The volume of soil excavated was 700,000 $m^3$ (915,600 CY). This amounts to about 73,000 $m^3$ per km of single track tunnel (153,363 CY per mile). About 150,000 $m^3$ (196,200 CY) of reinforced concrete and 10,000 tonnes (11,200 tons) of steel was used for the two Villejust tunnels. The construction of the 1,496 m Vouvray double-track tunnel proceeded at about 10 m (32 ft) a day using the "Austrian" technique of shotcreted temporary supports with anchoring. The cross sections of the Villejust and Vouvray tunnels are shown in Figure 7-6.

Several cut-and-cover designs were used in different locations. A technique for prefabricating the sidewalls and half of the covering plate was developed. The remaining sections were cast on site by pumping concrete over distances of up to 1,000 m (3,280 ft) (Chambron, 1986).

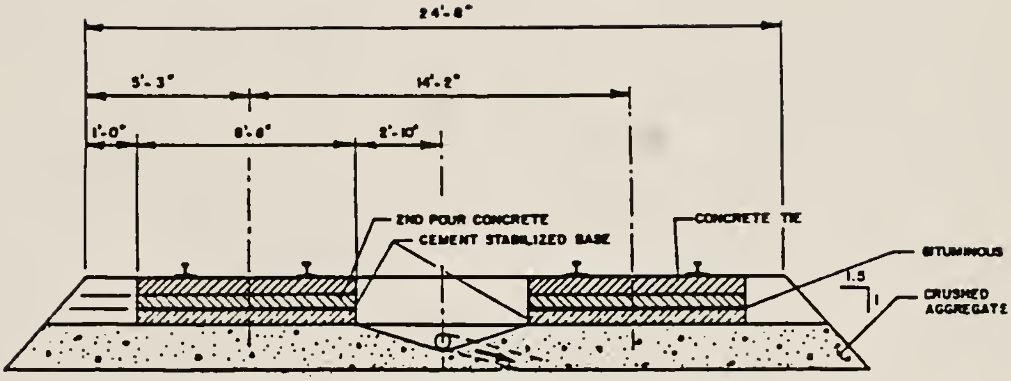
### Right-of-Way

The right-of-way cost depends on the track width, route location, and the alignment. A double track HSR requires a minimum right-of-way width of 12 m to 15 m (40 ft to 50 ft). Highway right-of-way and existing railroad tracks are not designed for high speeds. Additional land may be needed to smooth vertical curves. If the proposed route includes many

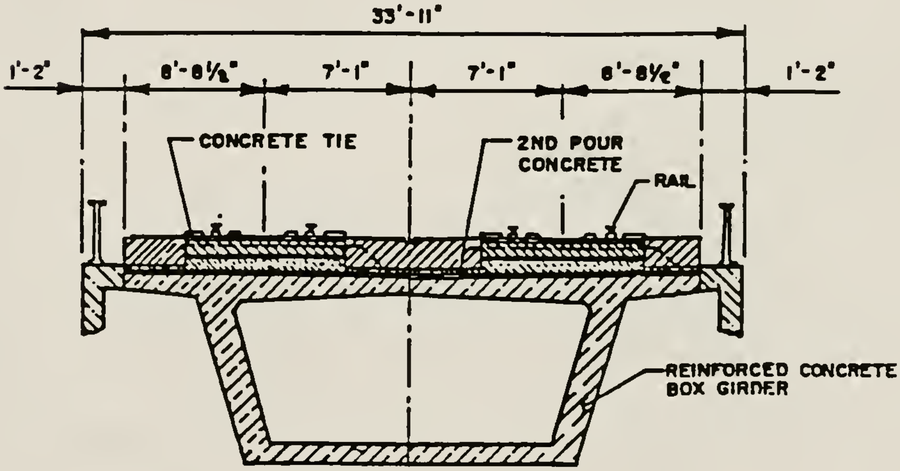
Table 7-6: Unit Costs of Railroad and Roadway Bridges for the X-2000 Tilt Train

| ROADWAY BRIDGES | COST PER UNIT (1993 dollars) |
|---|---|
| Lengthen overpass: 2 lanes | $644,000 |
| Lengthen overpass: 4 lanes | $978,000 |
| Lengthen overpass: 4 lanes divided | $1,211,000 |
| Embankment modification: 2 lanes | $259,000 |
| Embankment modification: 4 lanes | $313,000 |
| Embankment modification: 4 lanes divided | $367,000 |
| New overpass without walls: 2 lanes | $3,239,000 |
| New overpass without walls: 4 lanes | $4,136,000 |
| New overpass without walls: 6-8 lanes | $7,848,000 |
| New overpass with walls: 4 lanes | $6,343,000 |
| RAILROAD BRIDGES | COST PER KM (1993 dollars) |
| Trestle: wetland/single/cooper E60 | $4,521,000 |
| Trestle: wetland/dual/cooper E80 | $5,151,000 |
| Trestle: wetlands/single/cooper E60 | $7,114,000 |
| Trestle: wetland/single/cooper E80 | $9,000,000 |
| Elevated structure: 5m single/cooper E60 | $7,725,000 |
| Elevated structure: 5m dual/cooper E60 | $12,523,000 |
| Elevated structure: 7m single/cooper E60 | $7,943,000 |
| Elevated structure: 7m single/cooper E80 | $8,636,000 |
| Elevated structure: 7m dual/cooper E60 | $12,857,000 |
| Elevated structure: 15m single/cooperE60 | $9,053,000 |
| Elevated structure: 15m dual/cooper E80 | $10,328,000 |
| Elevated structure: triple track | $15,248,000 |

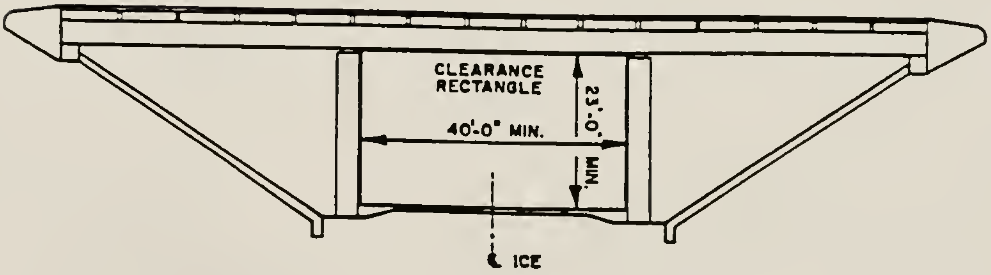
Source: adapted from FHSRC, 1990.



ICE Track Proposed for Texas



ICE Elevated Structure



Typical Roadway Overpass

Figure 7-5: ICE Track, Elevated Structure and Roadway Overpass
Source: Bordelon and Rozek, 1987.

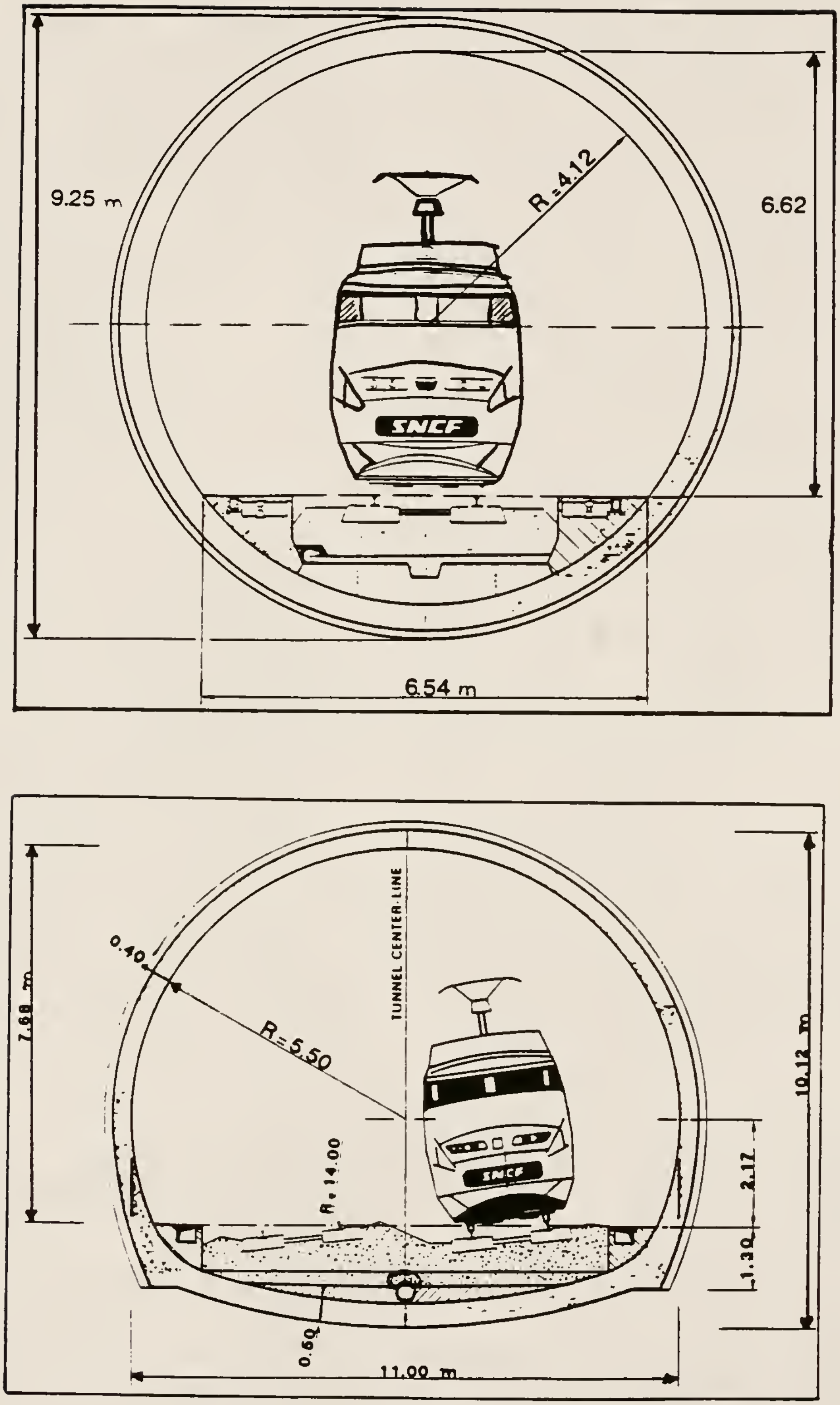


Figure 7-6: Single and Double-Track Tunnels for TGV
Source: Chambron, 1986.

curves, a tilt train technology may reduce the land cost by allowing higher speeds on existing curves.

The right-of-way cost can only be estimated on a site specific basis. However, some studies (BAAI, 1984; BAAI 1986) subdivided the land into core area, urban, suburban, and rural; and used a representative cost per acre for each type. U.S.G.S. and topographic maps and other real estate documents are needed to estimate the amount of land required and its approximate cost. Simulation runs help identify the most cost-effective curve excursions from existing rights-of-way.

### Stations and Maintenance Facilities

The advantage of HSR systems is that trains can access existing stations on conventional tracks. In the case a new station is planned, the cost can be estimated based on the structure type, the daily passenger volume, and the total station area. The cost of maintenance facilities is between three and five percent of the system's capital cost, depending on the number of trainsets and the frequency of operation. The TRB study (TRB, 1991) estimated a major maintenance facility would cost about $30 million, a satellite facility about $13.5 million, and a central control facility about $4 million.

Cost estimates for station platforms and parking spaces were provided by several studies. For instance, one study estimated the cost of a platform at about $17,000 per linear foot--costs are adjusted to 1993 dollars (BAAI, 1986). The costs presented in the Florida TGV proposal (1988) for new stations and for maintenance centers amounted to about 4.5% and 4% of the total capital cost, respectively.

### Rolling Stock

The cost of an HSR trainset depends on the technology and the number of passenger sections per train. A trainset carrying between 320 and 450 passengers costs between $10 million and $25 million. A TGV trainset with eight passenger sections (320 seats) costs about $16 million (Florida TGV, 1988). An ICE trainset with 14 passenger sections (780 seats) costs about $33 million (DM 53.2 million) (MVP, 1991). The X-2000 trainset with six passenger sections tested by Amtrak (325 seats) costs about $13 million (Pope, 1993). A Transrapid trainset with 10 sections (842 seats) costs about $48 million (DM 80 million) or $4.8 million per section (MVP, 1991).

### Miscellaneous

This category includes items such as utility relocation, fencing, application fees, underpasses for wild animals, environmental costs, waste disposal, management costs, and other costs not accounted for in the previous categories. A contingency cost percentage can be applied to each category or to the total amount. For instance, the TGV proposal increased all costs by 12% for contingency and insurance and 13% for design and management.

## Operation and Maintenance Costs of HSR Systems

The operation and maintenance of an HSR system include the following activities:

- Maintenance of equipments (MOE).
- Maintenance of way (MOW).
- Operating crew and on-board service crew.
- Station operation.
- Energy cost.
- Administration and Insurance.

The MOE cost, MOW cost, and energy cost account for about 75% of the total operating cost.

### Maintenance of Equipment

The MOE activity includes both daily tasks for routine maintenance and periodical tasks for major train overhaul. The maintenance of a TGV trainset with eight passenger sections and a power car at each end requires about 50 hours of labor per 1000 trainset-mile for routine inspection and preventive maintenance. Material and contracting costs amount to 0.0042% of the trainset's purchase price per 1000 km (0.0069% per 1000 mi) of operation. In addition, a crew of four workers is needed for daily cleaning. A major overhaul of the trainset is needed every 7.5 years. This amounts to about 3000 labor hours per year. The material cost for this activity is equal to 1.5% of a trainset's purchase price. The MOE cost accounts for about 20% to 24% of the total operating costs.

### Maintenance of Way

The MOW activity includes the tasks of maintaining the track, signals, catenary, and communication systems. The MOW cost varies with the type of operation and whether mixed traffic is allowed. Higher operating speeds require smaller tolerances for track misalignment. The MOW activity accounts for about 25% to 30% of the total operating cost.

The SNCF experience provides the following distribution of the labor required for MOW tasks (Brand and Lucas, 1989):

- Track: 220 hr/km (350 hr/mi) of track plus 9% for foremen.
- Signalling: 81 hr/km (130 hr/mi) of track plus 16% for foremen.
- Catenary: 81 hr/km (130 hr/mi) of track plus 16% for foremen.
- Communication: 31 hr/km (50 hr/mi) of right-of-way and 2 foremen.
- Other MOW: 31 hr/km (50 hr/mi) of right-of-way and 1 foreman.

The material cost for the MOW activity is based on the annual cost of replacement. This depends on the service life and expected cost overhead. The service life and overhead of main items are the following:

- Drainage and fence: 30 years service life / 20% overhead.
- Structures: 100 years service life / 12% overhead.
- Track and ballast: 30 years service life / 20% overhead.
- Signalling: 25 years service life / 12% overhead.
- Communications: 25 years service life / 12% overhead.
- Buildings: 50 years service life / 6% overhead.
- Stations: 50 years service life / 6% overhead.

### Road Crews

The operation of a TGV trainset requires one engineer per train with a 0.6 driving/duty ratio, and two conductors with a 0.75 work/duty ratio. This activity accounts for about 4.5% to 6% of the total operating cost.

### Station Operation

A station operation typically requires one manager, one supervisor, one assistant, and several ticket sellers based on demand and span of daily operation.

### Energy Cost

The energy consumption depends on the technology, the operating speed, the track alignment, the fleet size, and the operating frequency. A TGV trainset with eight passenger sections (317 to 380 passengers) consumes an average of 19 kWh/km (30 kWh/mi). Typically, the energy cost of HSR systems is about 15% to 25% of the total operating cost.

### Administration and Insurance

The administration and insurance costs depend on the fleet size and the operating frequency. The higher management staff generally consists of a president; six deputies for operation, finance, sales, engineering, human resources and purchasing; and about 35 middle managers. The administration cost includes the cost of insurance, advertising and promotions, and commissions paid to travel agents.

## Capital Cost of Maglev Systems

As mentioned earlier, Transrapid is the only very high-speed maglev system that is beyond the prototype stage. The Transrapid technology has been considered in numerous U.S. corridor studies. The description of the capital cost items presented in this section is largely based on the California-Nevada study conducted by Bechtel Corporation (1990). The main cost components of the California-Nevada system are shown in Figure 7-7. In general, the main cost items of a Transrapid maglev system are the following:

- Guideway including earthwork and grade separation.
- Guideway equipments.
- Electrification.
- Signals and communication systems.
- Maintenance facilities and stations.
- Vehicles.
- Design and construction management.

Depending on the terrain and the need for special structures, the guideway and earthwork costs account for about 55% to 75% of the total cost, and the guideway and wayside equipment plus electrification account for about 20% to 35% of the total cost.

### Guideway and Grade Separation

The guideway can be elevated or near-grade, made out of steel or reinforced concrete. The construction and placement of both steel and reinforced concrete guideway sections were

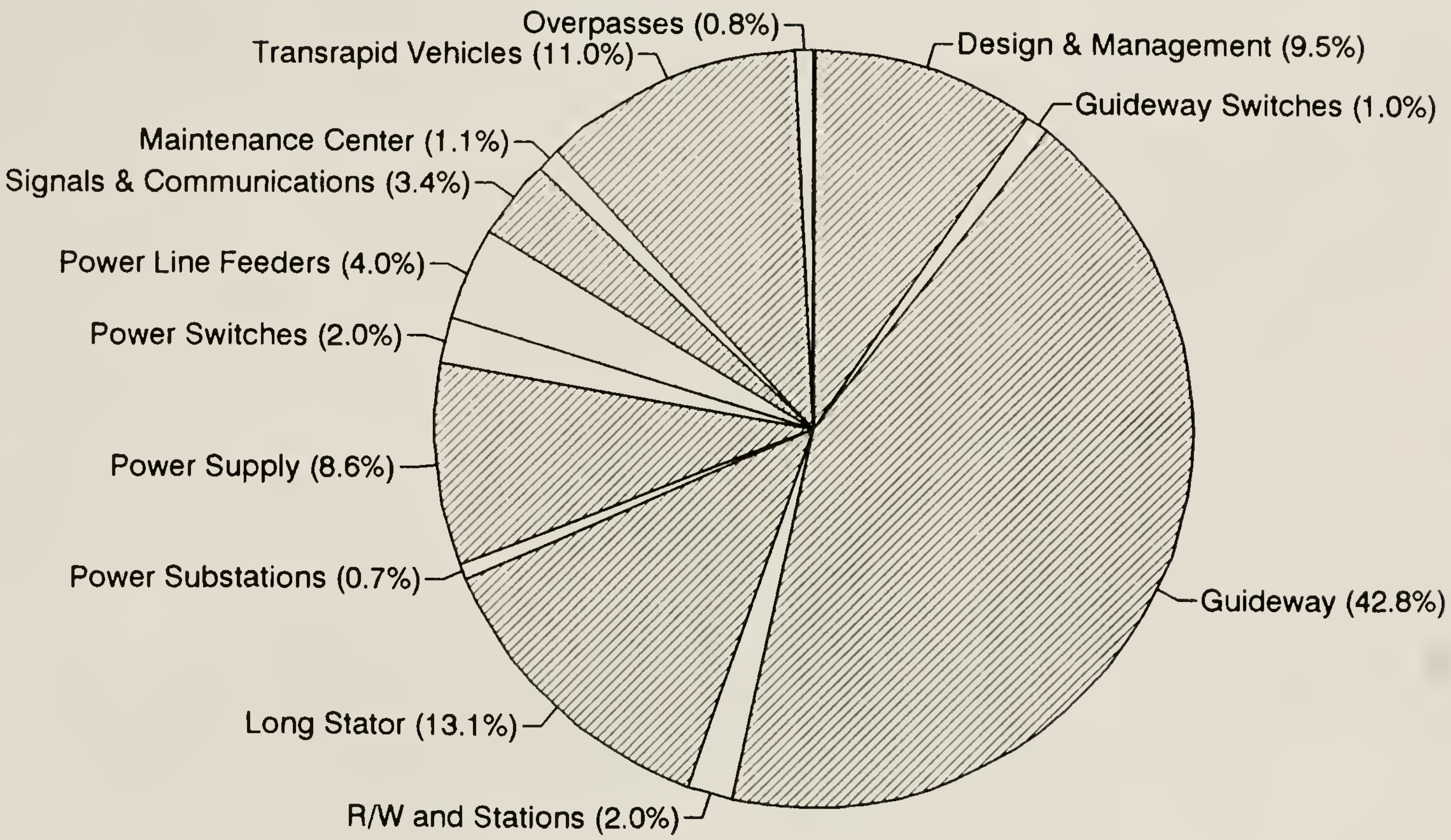


Figure 7-7: Cost Distribution of the California-Nevada Maglev Project
Source: Bechtel Corporation, 1990.

demonstrated at the Emsland testing facility in Germany (Hilliges and Scambeck, 1989; Schwindt and Kindmann, 1989).

Transrapid researchers determined that the optimal span for a concrete guideway is about 25 m to 31 m (82 ft to 102 ft). The typical column height is about 4.5 m (15 ft), although conceptual designs for columns as high as 40 m (131 ft) were developed. Computer-aided design, manufacturing and construction methods were developed for the concrete guideway. Guideway girders can be prefabricated and placed with assembly units up to a length of 35 m (115 ft).

The steel guideway uses a triangular cross-section and a tubular lower flange. The optimal span is about 25 m (82 ft). New fully automated robot methods were developed for welding the steel beams to insure a high work precision. Dimensions for each beam are computer-generated from layout and topographic data (Magnet Schnellbahn, 1991). A procedure was developed for precise measurement and positioning of the guideway. Surveying and distance measurements are performed with electro-optical devices that insure a mean distance error of less than 2 mm (0.08 in) (Marx and Stoeckl, 1989). Adjustable devices were used in the assembly of the individual structural components to achieve the strict tolerance requirements. The cross-section of the steel beam and the double track elevated guideway proposed for the California-Nevada project are shown in Figure 7-8.

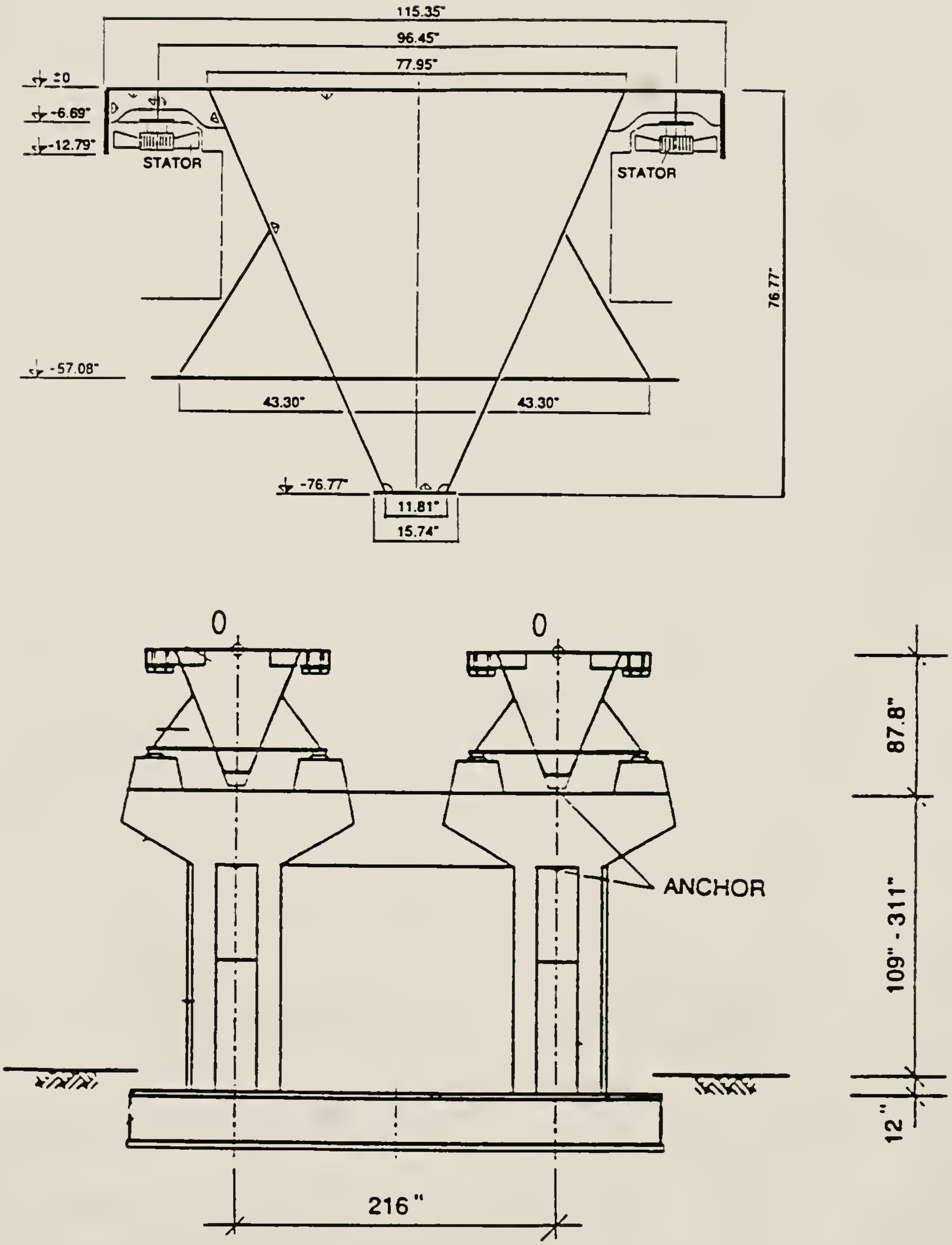


Figure 7-8: Cross-Section of Transrapid Guideway and Columns
Source: Bechtel Corporation, 1990.

The guideway cost includes the cost of surveying and clearing the ground, excavation, pile and spread foundations, pillars, steel reinforced concrete columns, and fabrication and transportation of the steel beams.

The quantities of material required per linear unit length of the guideway are the following:

| | | |
|---|---|---|
| Spread Foundation: | | |
| - Reinforcement steel: | 99.7 kg/m | (67 lb/ft) |
| - Concrete: | 0.29 $m^3/m$ | (3.2 CF/ft) |
| Columns: | | |
| - Reinforcement steel: | 59.5 kg/m | (40 lb/ft) |
| - Concrete: | 0.75 $m^3/m$ | (8.1 lb/ft) |
| Guideway Beams: | | |
| - Steel: | 1160 km/m | (780 lb/ft) |
| Guideway excavation: | 2.8 $m^3/m$ | (30 CF/ft) |
| Guideway switch: | | |
| - Excavation: | 300 $m^3$ | (24,720 CF) |
| - Foundation and columns: | | |
|   - Steel: | 37,200 kg | (82,000 lb) |
|   - Concrete: | 330 $m^3$ | (11,650 CF) |
| - Switch Beam: | 165,000 kg | (365,000 lb) |

A study dealing with maglev guideway costs is being performed by Parsons, Brinckerhoff, Quade & Douglas, Inc. The research is sponsored by the USDOT. The study classifies maglev guideways into 53 categories. The classification is based on guideway type (elevated, near-grade, tunnel, switch), number of track (single, double), location (urban, suburban, rural, interstate right-of-way), and topography (flat, undulating, rugged, mountainous). Cost per mile estimates are being developed for each guideway category. Table 7-7 presents the estimated cost breakdowns (including the long stator iron core and the lateral guiding rail) of a hypothetical double elevated guideway located in a rural area with an undulating topography. The table is based on an interim report completed in 1992 (USDOT, 1992). Other studies are being sponsored by the USDOT to estimate maglev construction costs. These studies, however, will not be completed before 1994.

Because maglev systems are typically elevated and are capable of up to 10% grades, the cost for special structures, earthworks, and for grade separation is lower than that of HSR systems. A typical crossing of an interstate overpass is illustrated in Figure 7-9. A study conducted by Pennsylvania High-Speed Intercity Rail Commission concluded that several tunnels through the Allegheny Mountains would be required to accommodate an HSR system, whereas fewer tunnels would be required for the maglev system because of its higher speed and great climbing ability (Schmelz, 1989; see also Appendix K).

### Guideway Equipments

The guiding and propelling magnets are located on the vehicle's undercarriage. The guideway contains the long stator pack, the three-phase stator winding, and the lateral guiding rails as previously illustrated in Figure 2-4. The rails are

Table 7-7: Cost Structure of a Maglev Guideway (1992 dollars)

| DESCRIPTION | UNITS | QUANTITY | UNIT COST | TOTAL |
|---|---|---|---|---|
| Clearing and Grubbing | ACRE | 3 | 5,900.00 | $17,700 |
| Earth Excavation (1500' haul) | C.Y. | 97,500 | 7.32 | $713,700 |
| Rock Excavation (haul 20 mi) | C.Y. | 32,500 | 34.00 | $1,105,000 |
| Footings | | | | |
| Structural Excavation | C.Y. | 3,300 | 10.50 | $34,650 |
| Form & Poor Concrete Footing | C.Y. | 980 | 230.00 | $225,400 |
| Install Piles (HP 14x89) | L.F. | 20,400 | 36.00 | $734,400 |
| Form & Poor Concrete Caps | C.Y. | 340 | 234.00 | $79,560 |
| Compacted Fill | C.Y. | 1,980 | 8.00 | $15,840 |
| Columns Form & Pour Concrete | C.Y. | 2,560 | 600.00 | $1,536,000 |
| Bearings | COL | 66 | 7,600.00 | $501,600 |
| Prestresses Concrete Guideway | | | | |
| Fabricate PC PS. Guideway | L.F. | 10,560 | 415.00 | $4,382,400 |
| Deliver and Erect Guideway | L.F. | 10,560 | 41.00 | $432,960 |
| Jack and Shim for Alignment | L.F. | 10,560 | 9.00 | $95,040 |
| Factory Installed Glide Steel Pads | L.F. | 10,560 | 70.00 | $739,200 |
| Vertical Guiding Steel Plates | L.F. | 10,560 | 204.00 | $2,154,240 |
| Long Stator Iron Core & Hangers | L.F. | 10,560 | 220.00 | $2,323,200 |
| Final Test & Calibrate Guideway | DAYS | 10 | 2,200.00 | $22,000 |
| Access Road 22' Wide | | | | |
| Aggregate Base 6" Thick | C.Y. | 2,150 | 15.00 | $32,250 |
| Binder Course 4" Thick | S.Y. | 12,900 | 8.00 | $103,200 |
| Wearing Course 4" Thick | S.Y. | 12,900 | 8.00 | $103,200 |
| Galvanized 6' Chain Link Fence | L.F. | 2,112 | 15.50 | $32,736 |
| Column Protection P.C. Concrete | EACH | 7 | 2,460.00 | $17,220 |
| Ditch Along Guideway | L.F. | 5,280 | 4.00 | $21,120 |
| Dewatering & Cofferdam | L.S. | 1 | 50,000.00 | $50,000 |
| Vegetation Control | L.F. | 5,280 | 2.00 | $10,560 |
| Surveying Cost | M.D. | 60 | 300.00 | $18,000 |
| Maintenance & Protection of Traffic | % | 1 | | $155,012 |
| Mobilization/Demobilization | % | 8 | | $1,252,495 |
| Total Estimated Cost per mile | | | $ | 16,909,000 |

Source: Harrison, 1992.

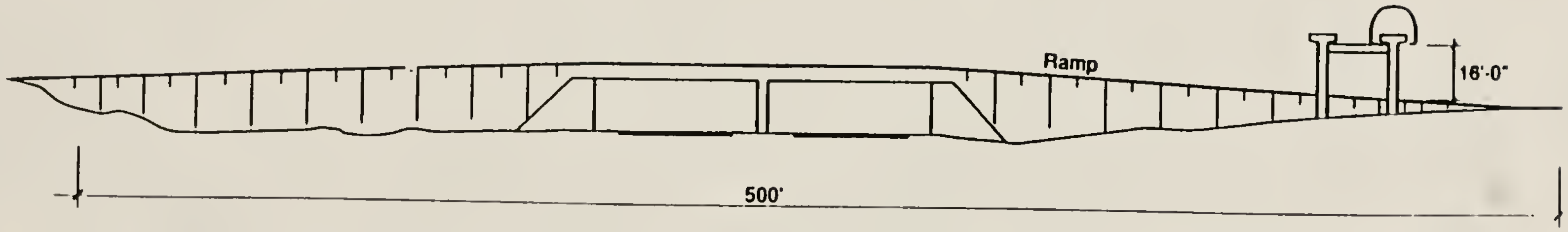


Figure 7-9: Typical Transrapid Roadway Crossing
Source: Bechtel Corporation, 1990.

made of high-grade steel and are factory welded. The stator consists of individual bundles of one-meter long lamination sections, and composed of 0.5 m (1.64 ft) thick magnetic steel sheets glued together. The three-phase stator winding consists of shielded cables held in an overlapping position by fixtures. A technique was used at the Emsland testing facility to mass produce the stator packs and the cable winding, and a computer-assisted process was developed to equip the beams with the electromagnetic components. A computer-controlled machine uses surveying alignments to determine the spatial position of the stator packs for each support. Drilling and electro-mechanical screwing are also computer controlled. The assembly of the windings on the guideway is performed with a specially designed vehicle that moves over the track and lays the windings at a rate of 2 m/min (6.6 ft/min) (Breitenbach et al., 1989).

The stator lamination weights about 200 kg/m (134 lb/ft) per single track. Each meter of track requires 14.4 m of winding cable (14.4 ft/ft). The cable's cross-section is about 2.7 $cm^2$ (0.42 $in^2$) of Aluminum or about 1.9 $cm^2$ (0.3 $in^2$) of cooper.

### Electrification

The electrification cost has fixed and variable components. The fixed cost elements are related to substations, land, and accommodation facilities. The variable cost elements are for the power line feeders, transformers, circuit inverters, circuit rectifiers, circuit breakers and switches. The estimated unit costs of these items for the California-Nevada project are shown in section B of Table 7-8 (1989 dollars). Circuit breakers are needed to energize the long stator linear-motor only for the section where the vehicle is traveling on. The track current is 1800 A at 6 kV and the inverters provide 12 MVA per unit.

### Signals and Communication Systems

All important communications between the train and the control center are redundant. The vehicle location is continuously monitored with a system that detects digitally encoded location marks along the guideway.

The signals and communication components include the mobile and stationary transmission equipments, wayside equipments and switches, and the control center. The estimated unit costs in 1989 dollars of these components are shown in section C of Table 7-8.

### Stations and Maintenance Facilities

Maglev systems cannot operate on existing tracks, and therefore require new stations or new access to existing stations. Because no maglev revenue system has been built, it is difficult to estimate the costs of such facilities. The California-Nevada project estimated that new stations would cost about two percent of the total capital cost, and the maintenance facility only about one percent.

Table 7-8: Maglev Capital Cost Items of the California-Nevada System

| DESCRIPTION (264 miles of double track) | UNIT | UNIT COST ($ Million) | QUANTITY | TOTAL ($ Million) |
|---|---|---|---|---|
| A. Double Track Guideway & Stations | | | | |
| 1. Elevated Guideway | mile | $9.192 | 126 | $1,158.19 |
| 2. Near Grade Guideway | mile | $6.624 | 138 | $914.11 |
| 3. Excavation & Backfill | M.C.Y. | $9.000 | 13 | $117.23 |
| 4. Crossing at Overpasses | each | $0.590 | 69 | $40.71 |
| 5. Switches: 2 way | each | $1.210 | 31 | $37.51 |
| 3 way | each | $2.100 | 7 | $14.70 |
| 6. Land & Stations | lump sum | | | $100.00 |
| SUBTOTAL A | mile | $9.024 | 264 | $2,382.30 |
| B. Power Supply | | | | |
| 7. Long Stator | mile | $2.537 | 264 | $669.77 |
| 8. Power Supply | substation | $12.294 | 19 | $233.59 |
| (20 kV and 115 kV) | MVA | $0.180 | 1152 | $207.36 |
| 9. Substation Construction | substation | $1.760 | 19 | $33.44 |
| 10. Motor Switches | | | | |
| Substations | substation | $0.590 | 19 | $11.21 |
| Double Track | module | $0.403 | 213 | $85.84 |
| Power Stations | module | $0.143 | 30 | $4.29 |
| 11. Power Line Feeders | mile | $0.765 | 264 | $201.96 |
| SUBTOTAL B | mile | $5.485 | 264 | $1,448.00 |
| C. Signals & Communication | | | | |
| 12. Mobile Transmissions | mile | $0.131 | 264 | $34.58 |
| 13. Wayside Equipment | subst.sec. | $5.590 | 18 | $100.62 |
| 14. Stationary Transmissions | mile | $0.052 | 264 | $13.73 |
| 15. Way Element Switches | module | $0.309 | 22 | $6.80 |
| 16. Control Center | each | $18.700 | 1 | $18.70 |
| SUBTOTAL C | mile | $0.661 | 264 | $174.40 |
| D. 17. Offices & Maintenance Centers | lump sum | | | $54.20 |
| E. 18. Design & Constr. management | percent | $12.000 | | $487.00 |
| F. 19. Vehicle | section | $4.710 | 120 | $565.20 |
| **TOTAL COST ESTIMATE** | **mile** | **$19.360** | **264** | **$5,111.00** |

Source: Bechtel Corporation, 1990.

### Vehicles

Both the California-Nevada and the Orlando projects estimated that Transrapid trainsets would cost about \$4.7 million per section. A trainset can consists of 2 to 10 sections. The weight per section is about 45 tonnes (50.4 short tons). The number of seats per 3, 5, 6 and 8 sections are 240, 408, 500, and 668; respectively.

The unit cost per Transrapid section used in U.S. feasibility studies includes the costs for spare parts, transportation, assembly, and commissioning.

### Design and Construction Management

The design and construction management cost varies between 10% and 20% of the total project cost, depending on the number of special structures and untypical sections. A study commissioned by the Transportation Research Board (TRB, 1991) presented the following cost estimates for preliminary engineering, final design, contingencies, and construction management as a percent of total cost:

- Preliminary design: 3% to 5%
- Final design: 5% to 10%
- Contingencies: 10% to 20%
- Construction management: about 8%

Cost contingencies are usually included in the unit cost of major components.

## Operation and Maintenance Costs of Maglev Systems

Maglev operation and maintenance activities are somewhat similar to those of an HSR system. They consist basically of MOE, MOW, Crew, Energy, and Administration. Unlike the TGV system which has been operational for over 12 years, the cost estimates for these activities for Transrapid are conceptual and based on findings and expert opinions of researchers at the Emsland testing facility.

### Maintenance of Equipments (MOE)

It is estimated that the maintenance of Transrapid trainsets requires annually about 1,793 hr per section of a trainset. The material cost for maintenance is about 25% of labor cost. In addition, cleaning the trainsets requires annually about 675 hr/section. The California-Nevada project assumed work efficiency of 90%, around 30% for fringe benefits, and 20% for overheads. Vehicle refurbishing is needed after 15 years of operation.

### Maintenance of Way (MOW)

The fixed facility annual maintenance requirement for Transrapid is estimated at 182 hr/km of single track (292 hr/mi). In addition, maintaining each guideway switch requires 55 hr annually. Large scale maintenance activities are required after 10 years of operation.

### Trainset Crew and Other Employees

Each trainset requires one driver and two to four attendants depending on the number of sections per trainset.

There is also a need for one traffic controller per station, two controllers at the control center, and one supervisor per power substation. The number of ticket sellers and other station employees depends on the passenger volume and daily span of operation.

### Energy Cost

Energy cost depends greatly on the average operating speed of maglev trainsets. Transrapid trainsets consume about one-third less energy per seat-km than HSR systems when traveling at comparable speeds. At higher speeds, however, Transrapid trainsets consume more energy per seat-km than HSR. As an illustration of energy consumption variation with speed, a Transrapid trainset with six sections (500 passengers) consumes 15 kWh/km (24 kWh/mi) at a speed of 200 km/h (125 mph), about 20 kWh/km (32 kWh/mi) at a speed of 300 km/h (187 mph), and around 30 kWh/km (19 kWh/mi) at 400 km/h (250 mph). In other words, Transrapid vehicles consume twice more energy per km when traveling speed goes from 200 km/h (125 mph) to 400 km/h (250 mph).

In addition, energy consumption for other purposes (e.g., switches, air conditioning, maintenance, stations, etc.) is on average about one-third of trainsets' consumption.

### Administration and Insurance

The administration and marketing costs can be estimated in a similar manner as described earlier for HSR systems. The insurance cost depends primarily on the system's safety.

Although theoretically Transrapid is safer than HSR systems because there is no risk of overturning; this safety advantage, however, has not been proven in revenue service under high frequency of operation. Chapter 4 provided a detailed description of Transrapid safety assessment.

## Capital Costs of Implemented HSR Systems

In this section, all costs are adjusted to January 1993 dollars. The Japanese Shinkansen Tokaido line linking Tokyo to Osaka is considered to be the first HSR line, although it initially operated at a moderate high speed. The line's cost was about $8.5 million per km ($13.5 million per mile). The cost for the Osaka-Okayama extension was approximately $11.4 million per km ($18.3 million per mile). The Okayama-Hakata extension was even more expensive because viaducts, bridges and tunnels accounted for about 80% of the route. This extension's cost was about $15.2 million per km ($24.3 million per mile) (TRB, 1991; Vranich, 1991).

The cost of the French TGV-SE line between Paris and Lyon was quite low because the line did not include tunnels nor many special structures. The cost was about $4.6 million per km ($7.3 million per mile) (Hopkins, 1990). The TGV Atlantic line required 7.6 km (4.75 mi) of tunnels and 3.4 km (2.1 mi) of viaducts and was designed for a higher operating speed. The cost was about $7.8 million per km ($12.6 million per mile) (Roth, 1990). Figure 7-10 presents the relative weight of the major cost components of the TGV Atlantic line (excluding the

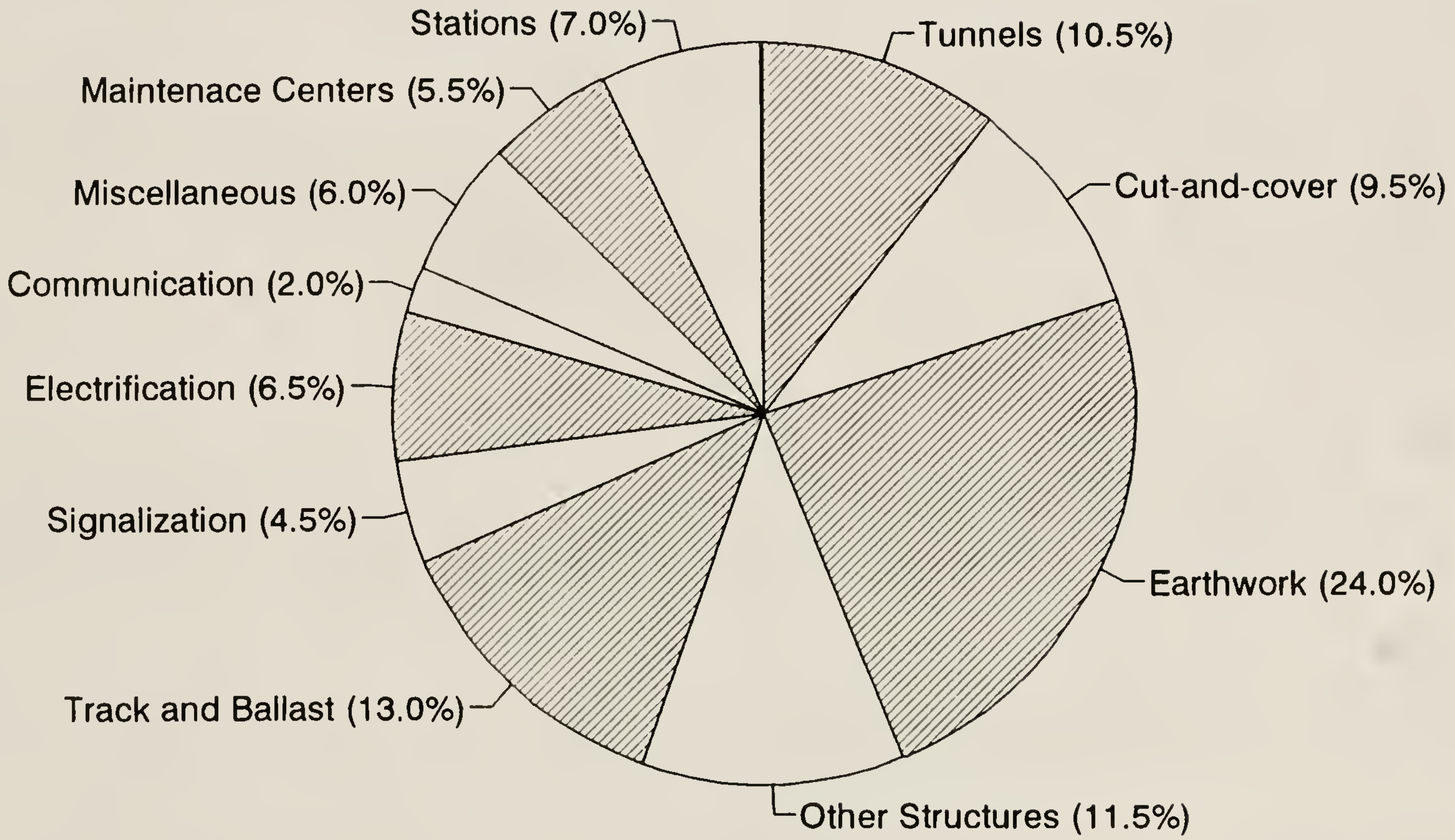


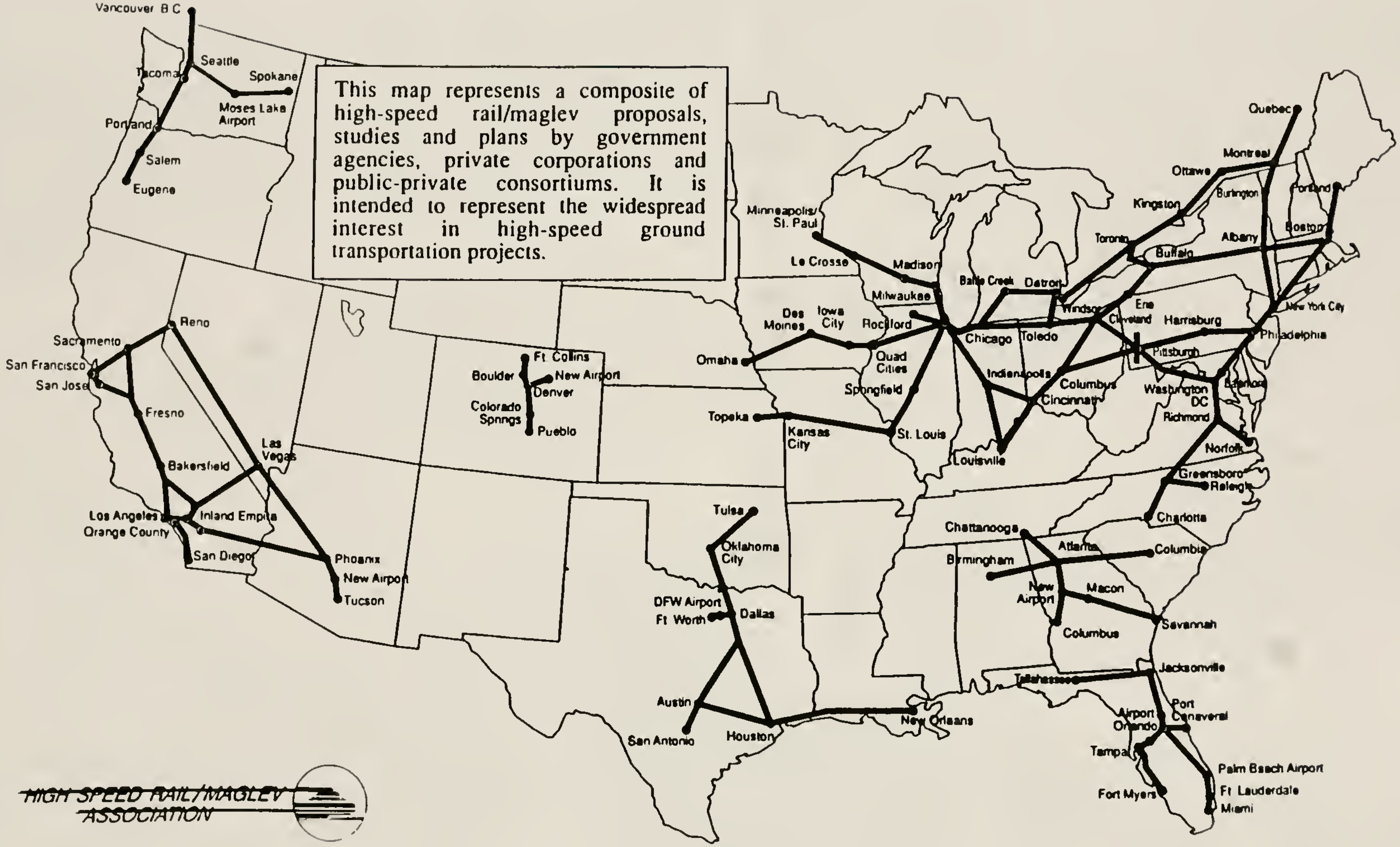
Figure 7-10: Capital Cost Components of the TGV Atlantic Line
Source: Chambron, 1986.

trainsets' cost). To reduce construction costs, the TGV new lines are designed for exclusive high-speed passenger service and served with uniform trainsets. Existing lines are used in urban areas to access existing stations at lower speeds (Roth, 1990; Leboeuf and Palade, 1986; TRB, 1991).

The cost of German ICE lines that opened in 1991 was about $19 (DM 30) million per km ($30.5 million per mile). In constant "dollar", the ICE lines were more than twice as expensive as the faster TGV Atlantic line because they crossed difficult terrain and were designed for mixed traffic with priority freight trains (ICE, 1992). The mixed traffic limited the allowable gradient to 1.25% instead of the 3.5% allowed on the TGV line, requiring numerous tunnels and special structures. The rail rested on a concrete slab to support higher axle loading (as opposed to the ballasted slab for the TGV). A more complex signalling system was needed to accommodate modular ICE trains and mixed traffic. Furthermore, the German legal system made the permitting process more difficult and numerous litigations prolonged the planning period (further details on the cost disparity were given in Chapter 2).

### Capital Cost Estimates of U.S. Corridor Studies

Figure 7-11 shows a broad perspective of all U.S. and Canadian corridors considered for HSR or maglev applications. All costs presented in this section are adjusted to January 1993 dollars unless stated otherwise. The Florida TGV proposal



This map represents a composite of high-speed rail/maglev proposals, studies and plans by government agencies, private corporations and public-private consortiums. It is intended to represent the widespread interest in high-speed ground transportation projects.

HIGH SPEED RAIL/MAGLEV ASSOCIATION

Figure 7-11: HSR and Maglev Corridor Studies in North America

estimated a ballasted double track system to cost about $4.8 million per km ($7.7 million per mile.) The proposed coastal line includes 10.5 km (6.54 mi) of elevated structures and no tunnels. The project also includes 127 bridges over roadways and 292 smaller bridges over water, but no major special structures is needed. The cost components of the TGV costal line are illustrated in Figure 7-12.

The TGV and ICE proposals presented to the Texas High-Speed Rail Authority contain comparable costs. Texas TGV proposal estimated a system cost of about $6.4 million per km ($10.2 million per mile) (Texas TGV Consortium, 1991). The Texas FasTrac proposal is based on the ICE system. Its estimated cost is 14% higher than TGV. Its cost is about $7.2 million per km ($11.6 million per mile) (Texas FasTrac, 1991). The Texas alignment contains few vertical curves and requires no tunnels. The Authority selected the Texas TGV proposal in 1991. A proposal based on the X-2000 tilt train was presented by FHSRC to the Florida High-Speed Rail Commission. The estimated system cost was about $7.4 million per km ($11.9 million per mile).

Maglev feasibility cost estimates are related to the Transrapid technology. The California-Nevada proposal estimated the cost of a 425-km (264-mile) double guideway Transrapid system at about $13 million per km ($20.7 million per mile). The proposed system has 69 crossings and no tunnels.

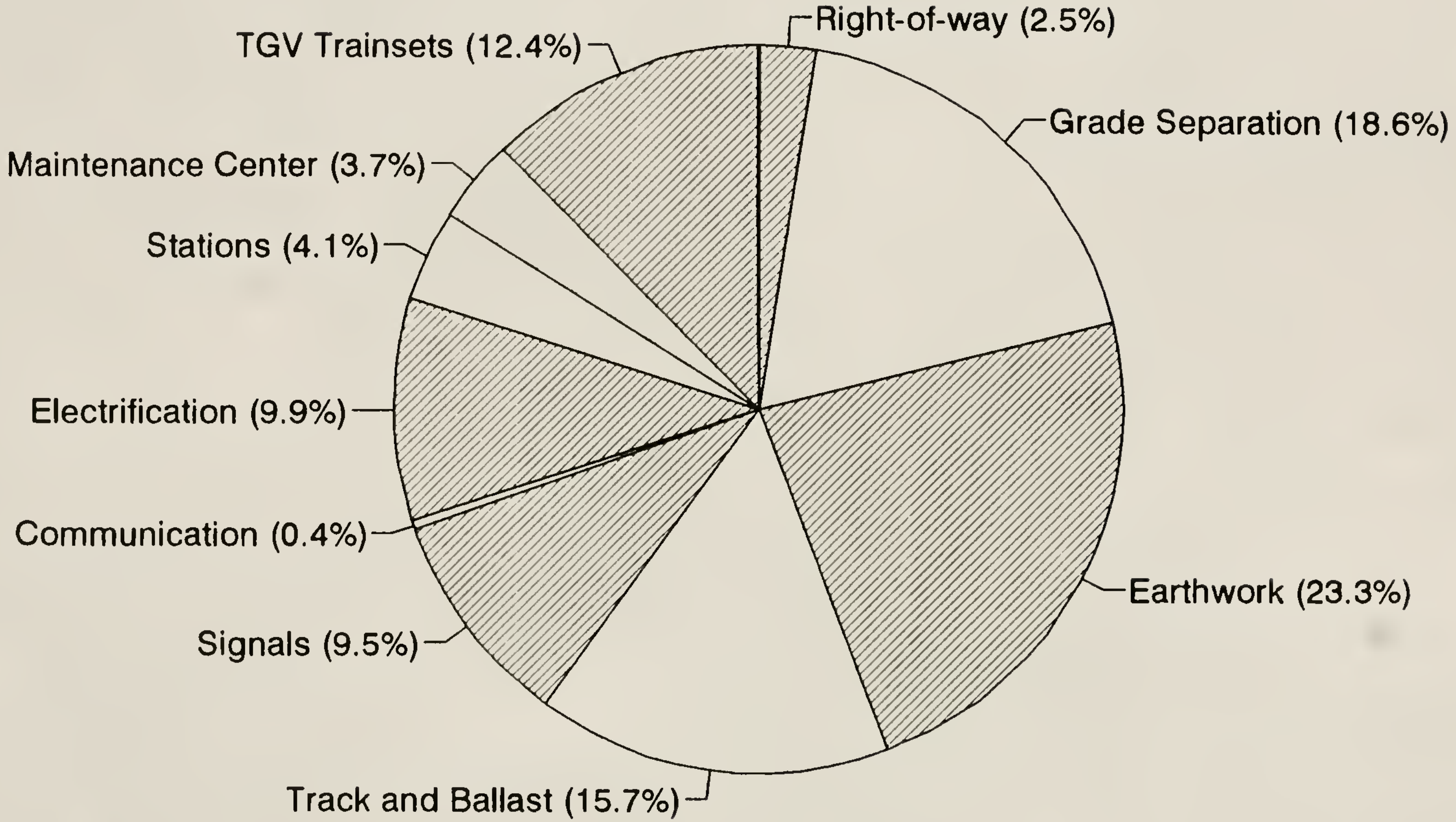


Figure 7-12: Capital Cost Components of the Florida TGV Proposed System
Source: Florida TGV, 1988.

An earlier feasibility study administered by the Pennsylvania High-Speed Intercity Rail Passenger Commission evaluated Transrapid and TGV technologies for a corridor 507 km (315 mi) long. The average system costs per double track route were about $17.8 million per km ($28.5 million per mile) for a TGV system, and $27.0 million per km ($43.2 million per mile) for a Transrapid system which is about 50% more than the TGV alternative (Schmelz, 1989). The justification given for the high cost of the TGV system is that the alignment crosses a very difficult and mountainous terrain and requires tunnels and rock excavation and disposal. The route contains a high percentage of rock, ranging from 86% between Harrisburg and State College to 41% between Philadelphia and Paoli. The Transrapid alternative requires much shorter tunnels and less rock excavation. About 80% of Transrapid guideway is near-grade (1.5 m or 5 ft high) and 13% is elevated. The remaining percentage is for aerial structures and bridges (Schmelz, 1989). Figure 7-13 shows the relative weight of the major cost components of the TGV and Transrapid systems. An estimate of the costs of TGV and maglev technologies for the Toronto-Ottawa-Montreal corridor produced a smaller cost disparity. In 1988 Canadian dollars, the total capital cost for a TGV-based system was $3.4 billion and the maglev alternative was $4.7 billion which is only about 38% more (Khan, 1992).

Table 7-9 presents the maglev cost estimates (adjusted to 1993 dollars) of corridors examined mostly in the early

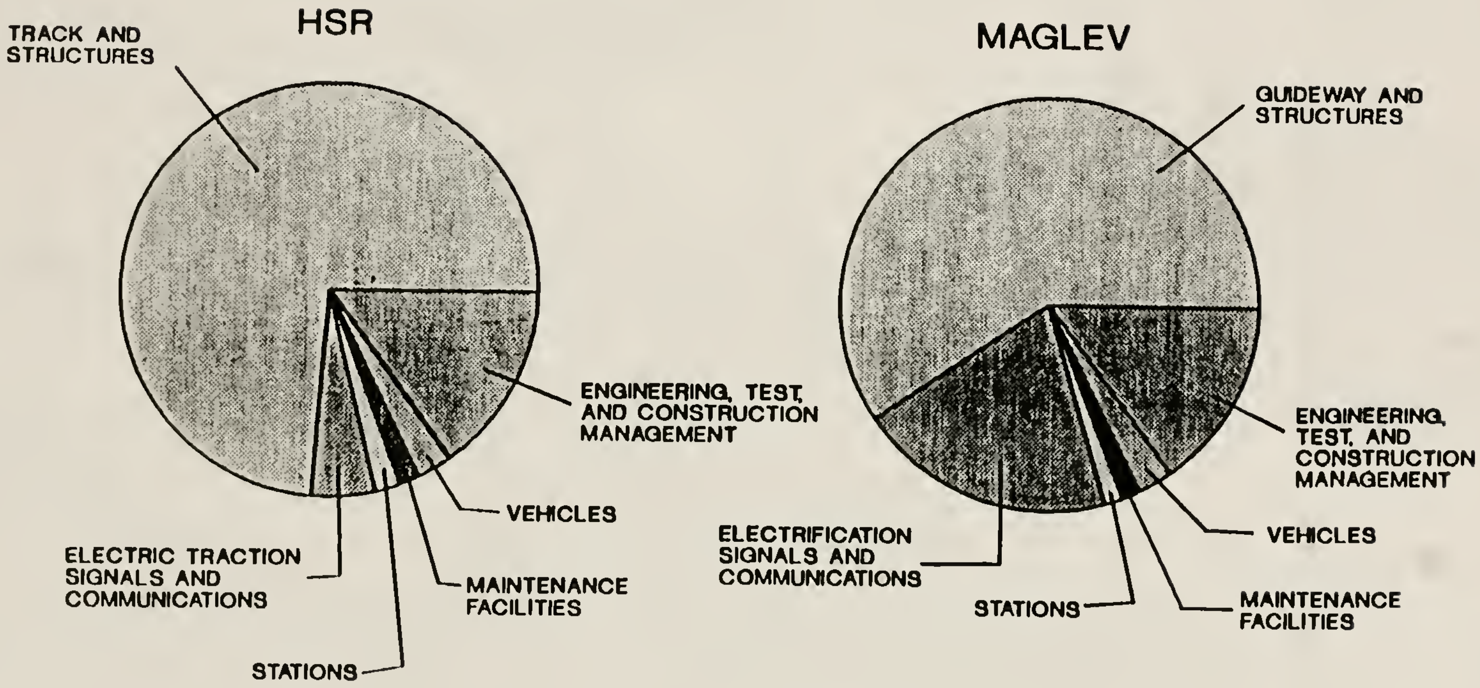


Figure 7-13: HSR and Maglev Cost Components for a Pennsylvania System
Source: Schmelz, 1989.

Table 7-9: Cost Estimates of Maglev Infrastructure Based on Corridor Study Reports (all costs in 1993 dollars)

| Corridor | Length mile | Study Date | Source or Sponsor | Cost M$/mile |
|---|---|---|---|---|
| Detroit-Chicago | 280 | 1985 | Michigan DOT | $19.8 |
| Philadelphia-Pittsburgh | 315 | 1986 | Pennsylvania High Speed Intercity Rail Commission | $43.2 |
| Montreal-Ottawa | 115 | 1984 | Canada Transportation Center | $14.6 |
| Vancouver-Portland | 342 | 1984 | Washington DOT | $52.0 |
| Tampa-Orlando-Miami | 314 | 1984 | Florida HSR Commission | $28.1 |
| Quebec-Windsor | 653 | 1984 | VIA Rail Canada | $11.5 |
| Las Vegas-Los Angelos | 230 | 1983 | City of Las Vegas | $17.1 |
| Las Vegas-Los Angelos | 267 | 1990 | California-Nevada Super Speed Train Commission | $18.8 |
| Toronto-Montreal | 376 | 1980 | Canada Transportation Center | $20.8 |
| Chicago-St. Louis | 282 | 1984 | Federal Reserve Bank of Chicago | $18.8 |
| F.Worth-Dallas-Houston | 296 | 1989 | Texas Turnpike Authority | $19.5 |
| Pittsburgh-Airport | 19 | 1990 | Maglev Working Group | $34.3 |
| Generic Assessment |  | 1990 | Federal Railroad Administration | $32.2 |
| Transrapid Assessment |  | 1987 | Transrapid International | $20.8 |

Source: adapted from CIGGT, 1986; TRB, 1991; FRA, 1990; TTA, 1989.

eighties. A study sponsored by the Transportation Research Board estimated the cost of hypothetical HSR and maglev (based on Transrapid technology) corridors (TRB, 1991). The study concluded that the capital costs estimates for an HSR system ranged from \$10.7 to \$11.5 million per km (\$17.1 to \$18.5 million per mile). The capital cost estimates for a maglev system were about \$17.5 to \$20.8 million per km (\$27.9 to \$33.4 million per mile).

### Estimates of Operating and Maintenance Costs

Estimates of operating and maintenance costs vary among studies. The feasibility study estimates range from \$0.032 to \$0.056 per seat-km (\$0.05 to \$0.09 per seat-mile) for HSR systems and from \$0.013 to \$0.063 per seat-km (\$0.02 to \$0.10 per seat-mile) for maglev systems. One recent study using hypothetical corridors (TRB, 1991) estimated that the operating and maintenance costs were about \$0.032 per seat-km (\$0.05 per seat-mile) for HSR systems and about \$0.025 per seat-km (\$0.04 per seat-mile) for maglev systems. If on average half the seats are occupied, then the estimated cost per passenger-km is twice the cost per seat-km.

### Development of a Preliminary Cost Database

A preliminary cost database was developed by gathering unit costs for HSR and maglev systems from the various feasibility studies examined in this report. The unit costs were adjusted to a base year of January 1993 by using the cost escalation factors shown in Table 7-1. Selected sections of the preliminary unit cost database are listed in Appendix J. It is important to note that the unit costs included in many maglev feasibility studies may be too low and the applied cost escalation factors may not reflect actual cost variations of specific components. However, the database developed is for the sole purpose of illustrating cost model. In the next chapter, guidelines are provided for developing a valid unit cost database that can be easily updated and expanded.

# CHAPTER 8
# CAPITAL COST ESTIMATION PROCEDURE

Preliminary cost estimation of HSR or maglev projects has traditionally relied on spreadsheet programs. Spreadsheet programs are easy to use, however, they suffer many limitations. This chapter describes a new cost estimation procedure that is based on a database software. The procedure is much simpler to use because it is controlled by customized menus. A sample cost model, written in dBase IV, was developed to illustrate the procedure.

## Limitations of the Traditional Method

The traditional method used for preliminary cost estimation of HSR or maglev projects consists of subdividing the route into small sections of few miles each, and then using topographic and land-use maps to determine the amount of earthwork, land requirement and the need for special structures. The cost items for each route section are stored in a separate spreadsheet file. The subtotal costs of all sections are added to determine the project's estimated cost (Schmelz, 1989).

If each route section is about 5 mi long, a 250-mi corridor would necessitate 50 spreadsheet files. Spreadsheet programs have limited ability to simultaneously manage multiple files, and there are practical limits for the size of each file. Furthermore, spreadsheet programs are not interactive and their query and macro capabilities are limited. Finally, customized input menus and formatted outputs cannot be easily generated.

## Advantages of a Database Software

A database software, such as dBase IV, offers several advantages. The most important advantages are the following:

- It can handle a very large size database allowing more detailed analysis.
- Menus can be generated for simplifying data input and providing useful instructions as well as help screens.
- It can incorporate programs written in the software's own language or in a host language such as SQL (Structured Query Language), FORTRAN, LISP or any other. These programs can be very complex, summarizing all useful tasks into series of commands that can be selected from a menu. This helps greatly in simplifying and automating the analysis process and capturing input errors. Furthermore, interacting with an object-oriented language such as LISP provides the ability to incorporate expert knowledge. For instance, an expert program can suggest the most appropriate types of subgrade and subballast layers and their respective levels of compaction, based on input values for soil type, water content, and trainset's maximum axle loading.

- It has considerable capability of parsing and manipulating strings. The model uses this feature to locate items and store values in the code file.
- There is a separation between the data, relations, and the programs that manage the database. Programs can be modified and new ones added at any time. This allows easy adjustment and upgrade of the model (Kroenke, 1992).
- Finally, an advanced feature of database software is that several databases can be linked and relational functions created to provide the capability to monitor and manage a construction project as large as an HSR or maglev project. For instance, the unit cost database can be linked with the database of construction items needed per route section; the material supplier's database; and with databases for contractors, supervisors and managers. This capability was illustrated with a model developed as a term project for a course dealing with relational databases. Several queries were written in SQL and included in the model. The entity-relationship diagram that specifies the overall structure of the linked databases and data relationships is shown in Figure 8-1. The translation of the entity-relationship diagram into relations is presented in Figure 8-2.

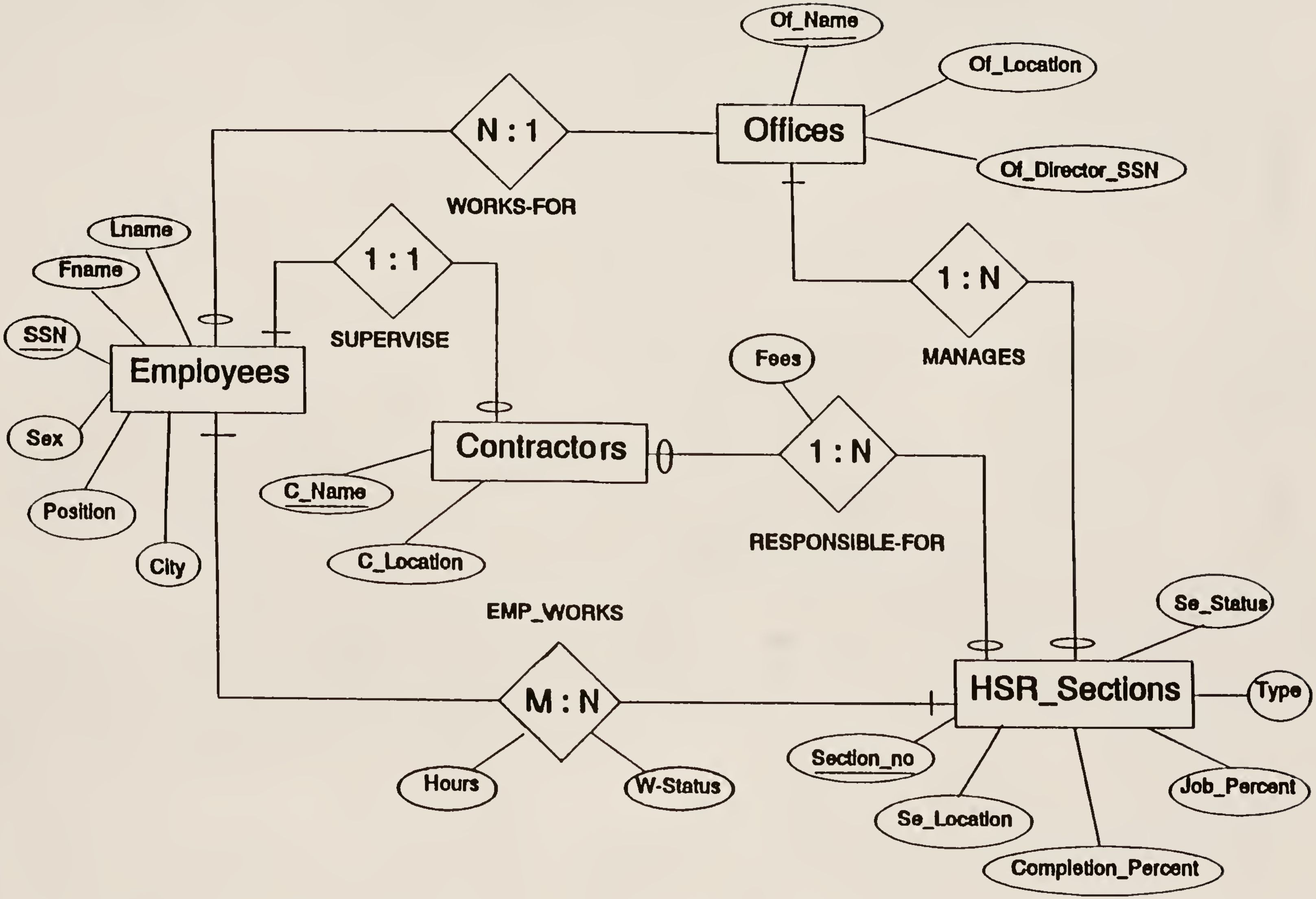


Figure 8-1: E-R Diagram for a Hypothetical HSR Construction Project

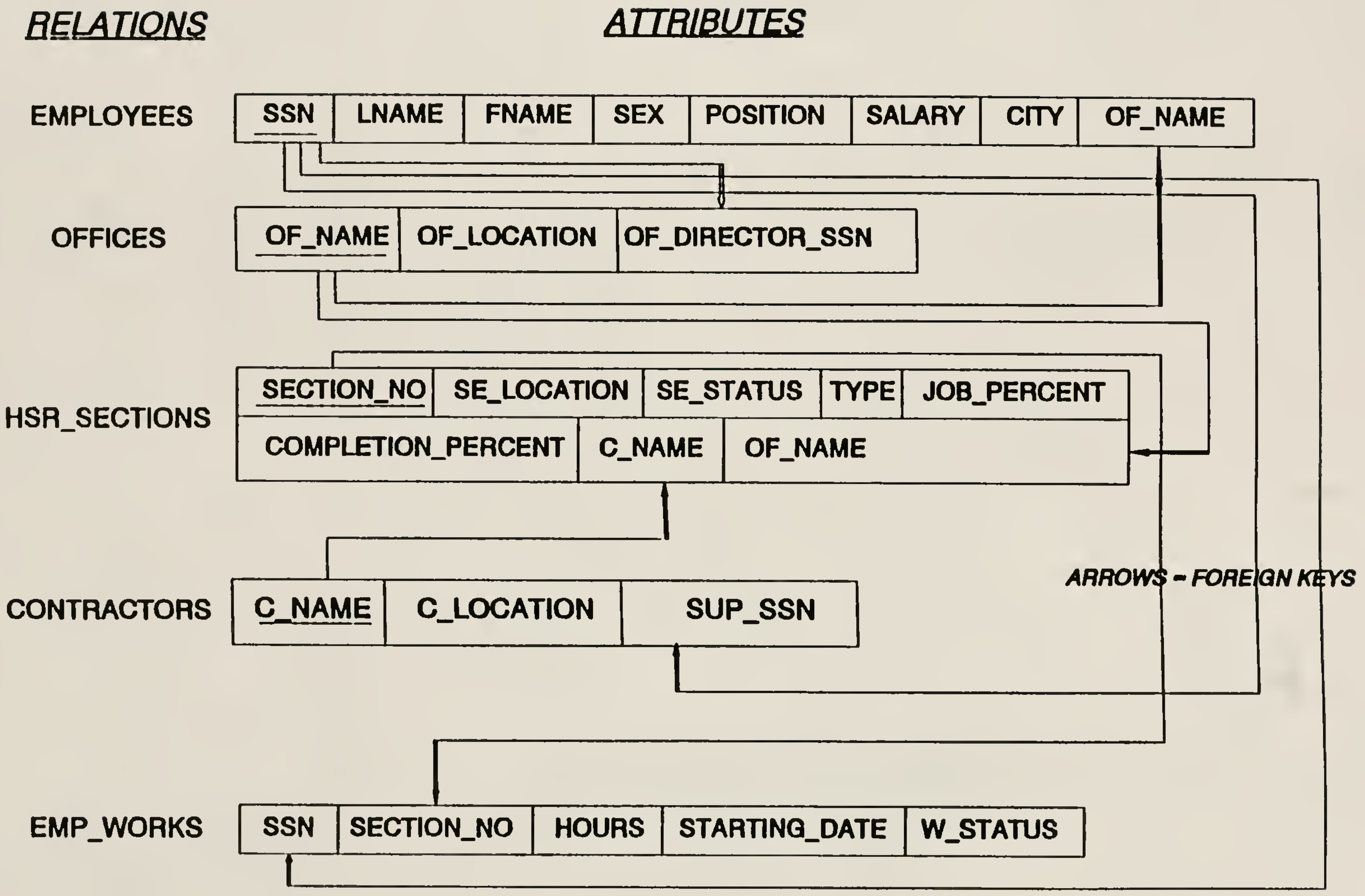


Figure 8-2: Translating the E-R Diagram Into Relations

## Proposed vs. Traditional Cost Estimation Methods

As mentioned above, the traditional preliminary cost estimation method consists of subdividing the route into sections and computing the costs of each section in a separate spreadsheet file. This is illustrated in Figure 8-3. However, combining, querying, or updating the various files cannot be easily performed. Furthermore, this method offers little flexibility in performing quick design changes or sensitivity analysis over the entire length of the route. Still, the most severe restriction is that unit costs are typically included in the spreadsheet files. As a result, updating the project's costs for another year or different unit costs has to be done separately for each unit cost and each section's file.

The proposed cost estimation procedure is designed to overcome the restrictions of the spreadsheet-based method described earlier. Furthermore, the procedure is simpler, faster and easier to upgrade. It also benefits from all the advantages cited above because it relies on a database software. The disadvantages of the proposed procedure are that it requires writing complex programs and adopting a uniform coding system for capital cost items. These programs, however, need to be written only once and occasionally updated. In addition, a detailed unit cost database of main items needs to be developed.

The proposed method handles the individual costs of all sections simultaneously because all cost items of every route

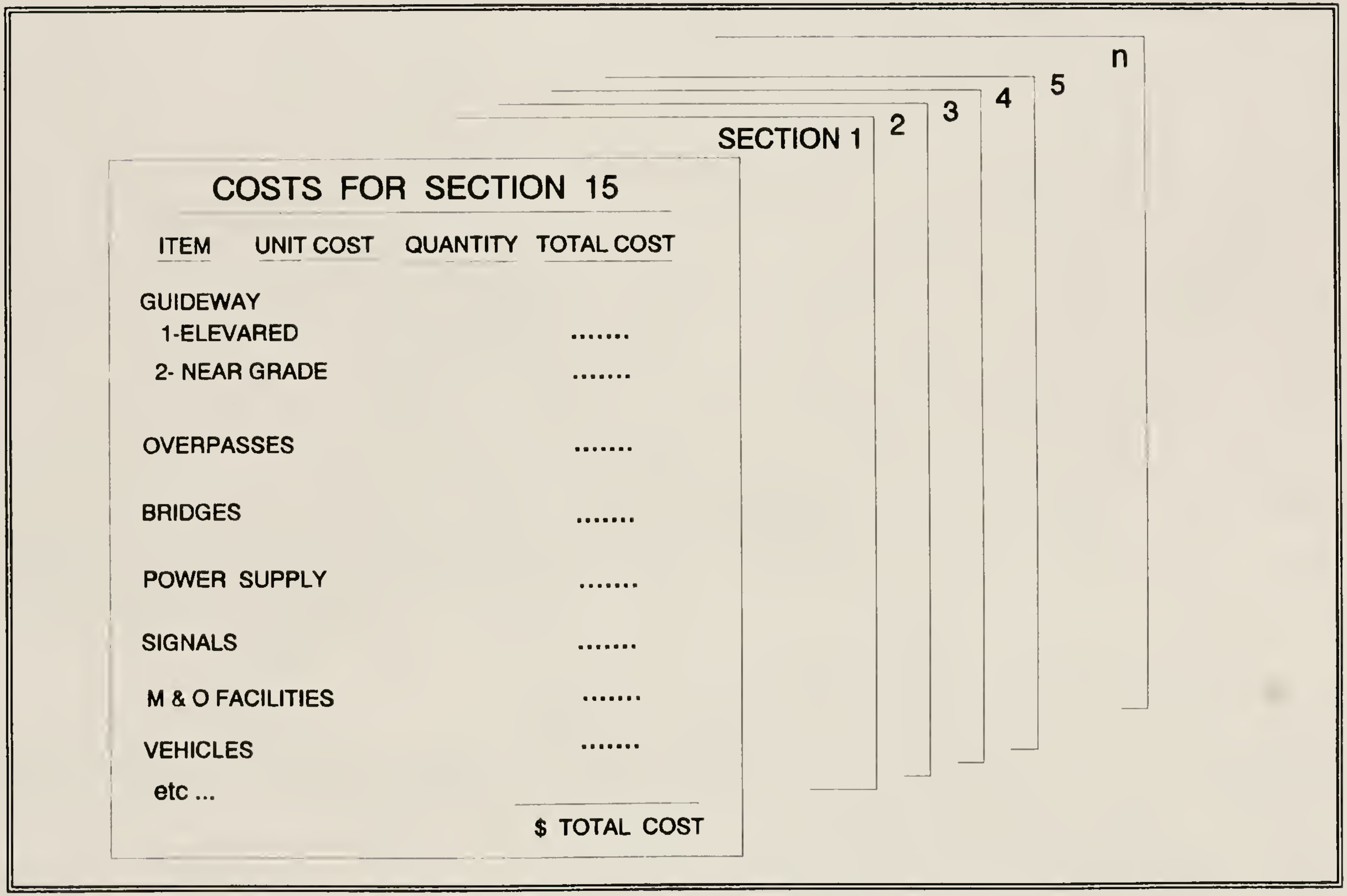


Figure 8-3: Cost Summary of Main Items Per Route Section

section are stored into one large database file. Each route section is represented by one record of the file. There is no practical limits for the number of route sections that can be analyzed. The dBase IV software, for instance, can manipulate a file of up to one billion records. Managing, updating and querying a large file are all basic operations that can be easily performed by any database software. A database file may be actually stored in several files. This is, however, an internal operation of the software that is hidden from the user. For practical purposes, a database file can be considered as one file.

The procedure overcomes the second restriction of the spreadsheet technique because one command can modify the data in a specific field for one, few, or all route sections simultaneously. Furthermore, one or more conditions can be added to the command so that only route sections that satisfy these conditions are affected. These commands can be entered interactively or stored in a program that can be called from a menu. Another important feature of database software is their considerable flexibility in locating and modifying selected items from the database file. This greatly simplifies the task of performing design changes or sensitivity analysis.

Finally, the best feature of the proposed method is that it can interact with any unit cost database that uses the specified coding system to produce preliminary cost estimates of an HSR or maglev project. In other words, there is a separation between the project's construction items and their corresponding unit costs. They are stored in separate files.

## Structure of the Cost Estimation Method

The capital cost estimation procedure is based on a spreadsheet software and a strict coding system used by the model to locate items. Preliminary cost estimates are generated in two steps: first, a file is generated that contains the listing of all the project's item codes, subdivided by route section; then the model interacts with a separate unit cost database and replaces each item code with its corresponding unit cost. These operations are easily performed with customized menus. The model's structure is illustrated in Figure 8-4.

### Main Menu

The main menu directs the user to the desired application. The user can begin generating a code file, updating an existing one, edit a unit cost database, generate a cost file, or produce cost summaries.

### Code-Generating Menus

There are two separate code-generating menus; one for high-speed trains, the other for maglev. The maglev menu of the sample model is illustrated in Figure 8-5. The code menu allows the user to select project items. Individual items are grouped into greater project units and represented by a hierarchical coding system (Nassar and Najafi, 1992). For example, Transrapid's power supply includes substations,

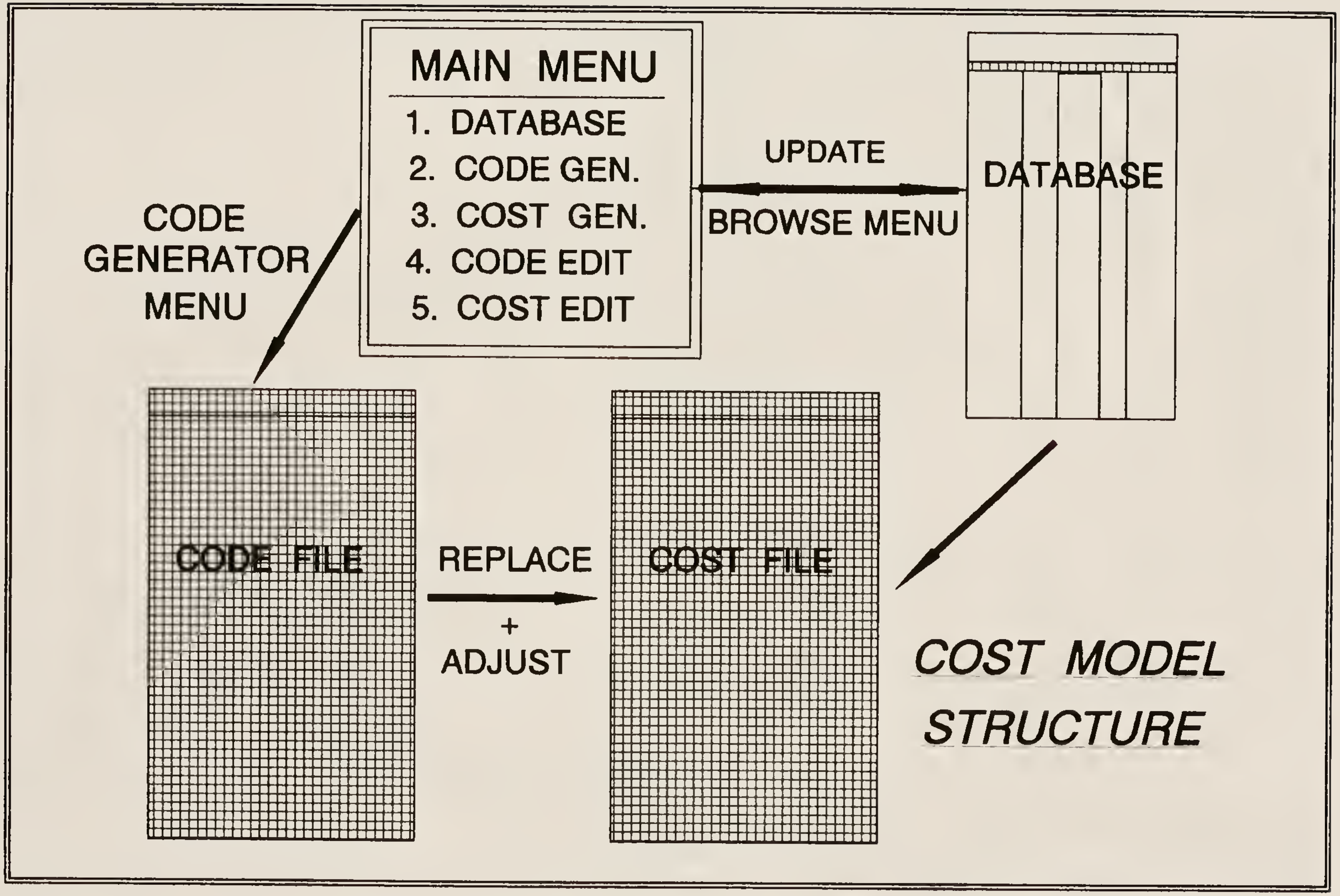


Figure 8-4: Overall Structure of the Cost Estimation Procedure

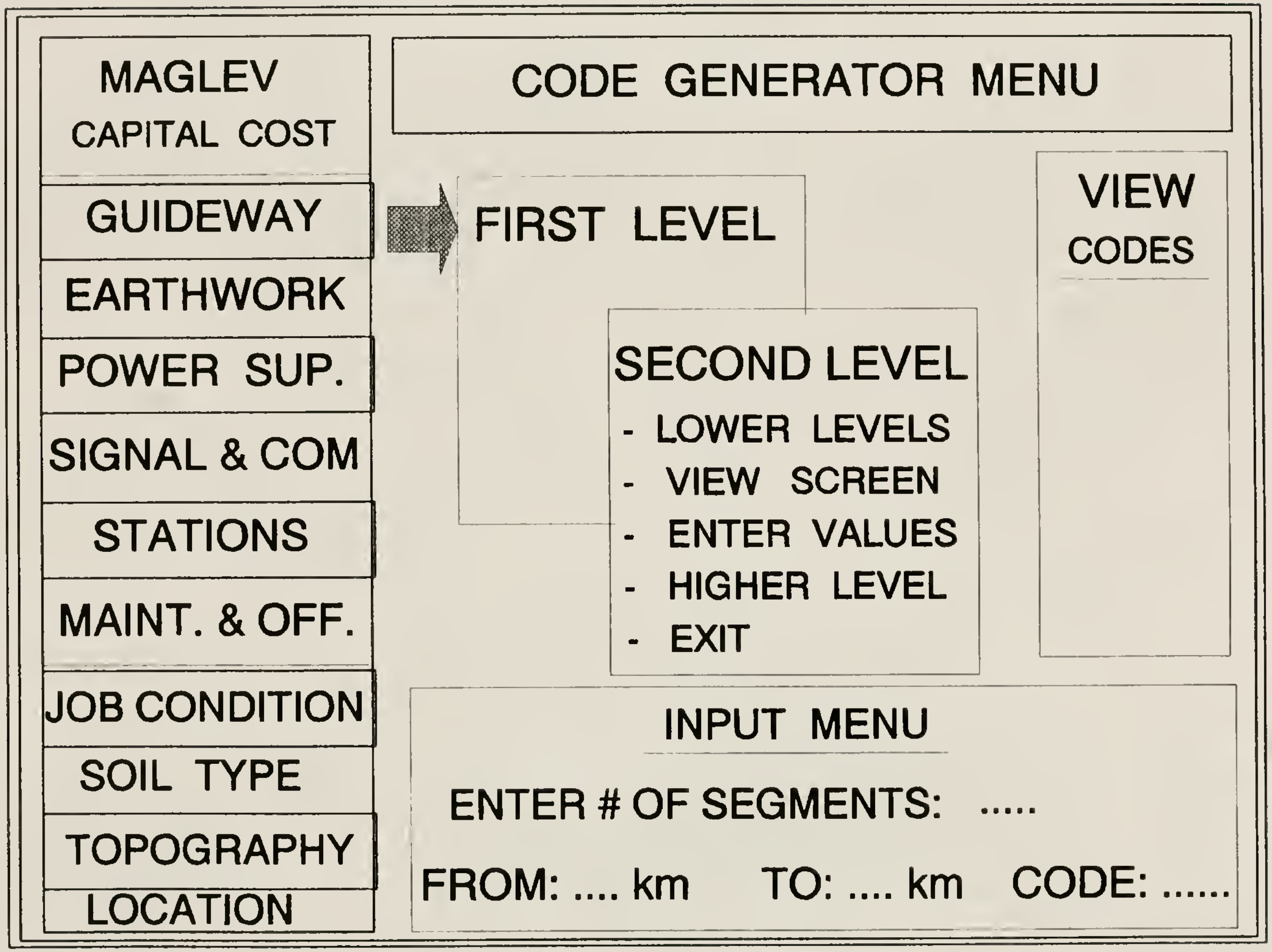


Figure 8-5: Code-Generating Menu For Maglev Capital Cost Items

control power, electric switches, and power feeders; and TGV's track consists of rail, ties, fasteners, ballast and subballast.

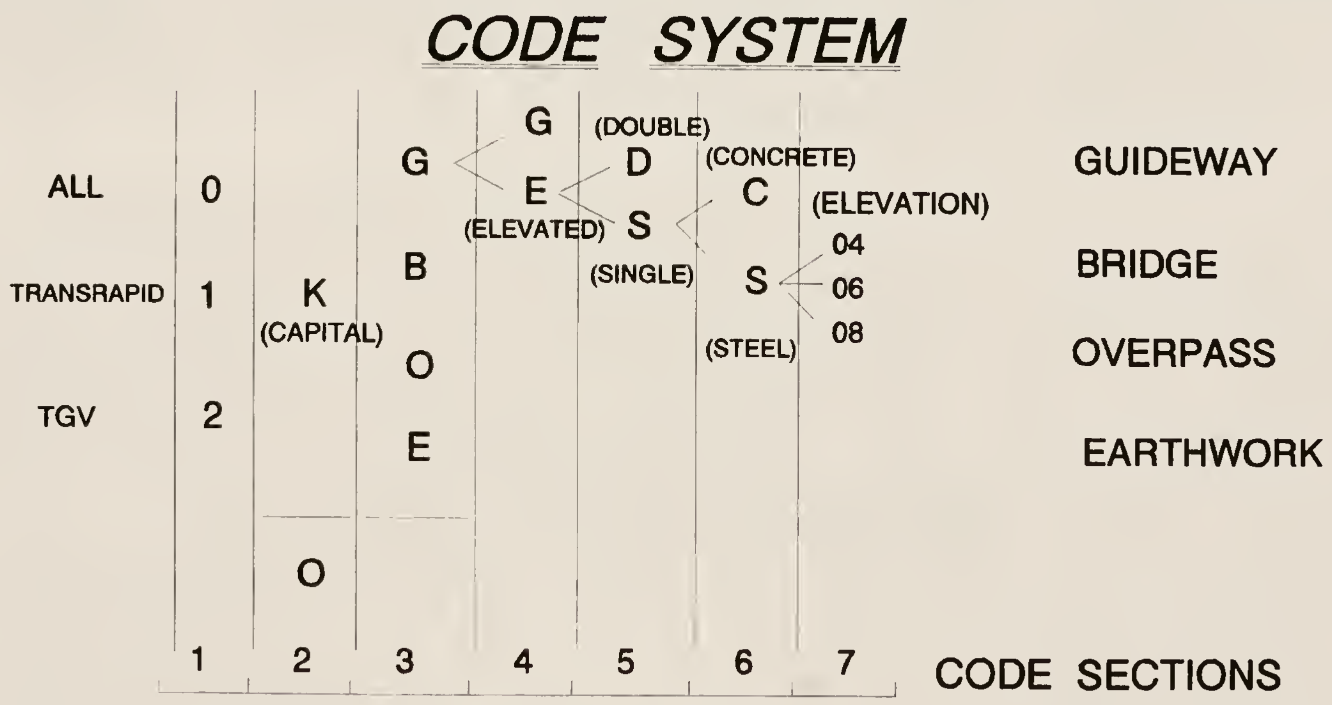
The procedures to generate project codes and build the code file are as follows: First, the user selects a category from the menu displayed on the screen's left side. Depending on the category, it may have one, two, or more submenus to select from. At each time, the codes of the selected subgroups are viewed in the "View Code" window located on the right side of the screen. Fewer codes are shown at lower-level menus because the model's "LOCATE" function becomes more restrictive. Once the desired item is located, its code is stored at desired cells in the code file using the "Input Menu" window located at the bottom of the screen.

The route is subdivided into small sections of about one mile each. Menus provide an efficient way to enter data. For example, to select an elevated single concrete guideway four meters high for route sections 300 to 900, only one entry is required and the model generates the corresponding code for all 600 route sections and store these codes in the "Guideway" field of the code file.

### Coding System

The coding system is a hierarchical classification method similar to the method used by libraries for coding books. Each code has several alphanumerical components. Each component is a subgroup of the component to its left. The coding system can be visualized as a tree structure where nodes allow the selection of desired branches. Nodes are represented in the model by lower-level menus. The codes for all branches of one node must have the same number of digits. For example, the code component that represents guideway elevation must have two digits because an elevated guideway can be over 10 m high. Therefore, the elevation of a guideway that is four meters high must be written as "04" as shown in Figure 8-6.

The coding system used for the sample model is as follows: the first section of the code is a number that represents a technology (e.g., "1" for Transrapid, "2" for TGV, etc.); the second section is a letter (e.g., "K" for capital items, "O" for operational items). The third and subsequent code sections are additional levels of detail. There is no limit for the level of detail because the code component to the right can still be broken further and new subcodes appended to the right of initial code. This does not affect how the program locates items. For instance, to display all TGV capital cost items, the program will select all items starting with "2K" regardless of the number of subgroups. To display all Transrapid choices for a guideway that is six meters high, double, and made of reinforced concrete; the program locates and displays all items starting with "1KGEC06" regardless of the number of subgroups (or branches) for this "parent" code. In dBase IV, the command to locate the above mentioned Transrapid guideway is the following:



| EX: | | |
|---|---|---|
| | 1 K G | TRANSRAPID GUIDEWAY |
| | 1 K G E | TRANSRAPID GUIDEWAY ELEVATED |
| | 1 K G E S | TRANSRAPID GUIDEWAY ELEVATED STEEL |
| | 1 K G E S 04 | TRANSRAPID GUIDEWAY ELEVATED STEEL 4 m. HIGH |

Figure 8-6: Code System Used to Locate Items

```
LIST OFF CODE FOR LIKE ("1KGEC06*", UPPER(CODE))
```

The command to store the guideway code in the code file for the 600 route sections described earlier is the following:

```
REPLACE GUIDEWAY WITH '1KGESC04' FOR SECTION >= 300
          .AND. SECTION < 900
```

Where CODE, GUIDEWAY and SECTION are field names.

The process of storing item codes in the code file is repeated until all project's items are included. The model stores the codes of each route section in one separate record (row) of the code file. Each item category (e.g., guideway, highway bridge, rail bridge, etc.) is represented by a separate field (column) of the same file. A technique was developed to include both the item's code and its quantity into one database cell. When the code file is being generated, the item code and its corresponding quantity are appended together and separated with a hyphen. The compound code is then stored into one database cell. Later when the cost file is being generated, cell entries are parsed and each item's code is separated from its quantity. In dBase IV, the "AT" function returns the position of a substring (a hyphen in this case) within a string, the "LEN" function returns the number of characters in a string, the "LEFT" and "RIGHT" functions return a specified number of character to the left or right of the string. The code file is illustrated in Figure 8-7. Columns two to four of the code file are used to adjust the various unit costs of the corresponding route section.

### CODE FILE

| SECTION | SOIL | TOPOG. | JOB COND. | GUIDEWAY | OVERPASS | EARTHWORK |
|---|---|---|---|---|---|---|
| 1 | A | F | F | GDC | - | X-500 |
| 2 | A | F | G | GDC | - | X-850 |
| 3 | B | U | F | GEC04 | N2S | B-600 |
| 4 | C | U | P | GES06 | - | B-200 |
| 5 | C | U | P | GES08 | R4C | X-1200 |
| 6<br>Etc. |  | F = Flat<br>U = Undulating | F = Fair<br>G = Good<br>P = Poor |  | NES = New 2 Lanes Steel<br>R4C = Rebuilb 4 Lanes Concrete | X = Excavation<br>B = Backfill |

Figure 8-7: An Illustration of a Code File

## Cost File

Finally, after the code file is completed, the model duplicates it and replaces each item code with its corresponding unit cost. In dBase IV, this is done by using the "LOCATE", "LOOKUP" and "REPLACE" functions. After parsing the compound codes, the program search the unit cost database to locate the corresponding unit cost of each code. For each cell, the item’s unit cost is multiplied by its quantity and the result is stored in the cell. This operation is repeated for all code file’s cells, except for the cells in fields that are used to adjust other costs, such as the first four fields shown in Figure 8-7. Programs can be written to adjust the costs of guideway, bridges, and other structures for soil type, job condition, location, and so on. Several adjustment factors can be used depending on the construction type. More complex programs can be written to perform a variety of functions such as checking input values for reasonableness, insuring each route section has a guideway or track code, using expert knowledge to verify that selected structures are compatible with soil type, axle loading, and so on.

Because the cost items for all sections are stored into one database file, managing the construction costs of several route sections are easily performed by the software. Menus were written to provide various types of useful queries and cost summaries.

The preliminary estimate of the project's total cost is determined by adding all the rows and columns of the cost file. The total cost of a route section is determined by adding the values stored in one row corresponding to that section. The total cost of an item category such as elevated guideway is determined by adding all the values in the "Elevated Guideway" field. Users can easily customized their own cost summary menus and query commands to fit their specific needs.

Finally, the model's best feature is that it can be upgraded without changing its internal structure. For instance, if new items are added to the unit cost database and the coding system is respected, then these items will be automatically accessed by the menus and used in the analysis. This avoids all normalization problems common in linked databases.

# CHAPTER 9
# CONCLUSIONS AND RECOMMENDATIONS

## Conclusions

This research presented a technical description of the various HSR and maglev systems available today. The capital and operational cost structures of these systems were also described. In Chapter 5, train dynamic theories were presented. Based on these theories, an operational simulation model was developed and described in Chapter 6. The operational model accounts for system performance characteristics, route alignment (i.e., grades and curves), imposed speed restrictions, station locations, track superelevation, and allowable lateral acceleration. Sensitivity analysis can be easily performed. For instance, to evaluate the operational impacts of adding one intermediate station, only one code line (consisting of two numbers: location and dwell time) needs to be added to the route file.

Capital and operational cost components of the various technologies were presented in Chapter 7. The cost information was derived from the U.S. feasibility studies, which in turn were based on the European experience where HSR systems have been implemented. A cost estimation procedure that relies on a database software was described in Chapter 8. The procedure was illustrated with a sample model. A comparative description of the various technologies is presented next.

Performance

The maglev technology significantly outperforms the HSR technology. Maglev trains are capable of much higher speeds because they operate without contact with the supporting guideway. They are also capable of higher acceleration rates because the vehicle's frame is made of lightweight material, and part of the propulsion system (the winding cable) is located on the guideway. Maglev trains are also capable of climbing significantly higher grades due to the stored kinetic energy that increases by the square of the speed. Finally, maglev systems are less affected by horizontal curves than HSR systems because of their higher allowable banking angle, which reduces lateral acceleration.

The results of the study cases indicated that Transrapid was about 30% faster than the leading HSR systems. The TGV system outperforms the ICE and the X-2000. The X-2000 tilt train can travel about 25% faster on curves. However, its top speed is limited because of its flexible trucks. Furthermore, it requires a complex tilting mechanism. The X-2000 is a good option for existing lines where curve improvement is very costly. But it requires expensive route electrification. New lines can be built with higher superelevation rate than existing lines designed to accommodate freight trains. Furthermore, new lines can be designed with better alignment because of HSR greater climbing ability. Therefore, TGV and ICE systems are more appropriate for new lines.

### Energy Consumption

A maglev system consumes less energy per mile than an HSR system when traveling at a comparable speed. However, the purpose of investing in a maglev technology is to operate at higher speeds than is possible with HSR systems. Maglev energy consumption increases rapidly with speed, and at very high speeds the consumption rate per mile is higher than that of HSR systems. For instance, Transrapid requires twice as much energy per mile when its speed goes from 200 km/h to 400 km/h. The energy consumption rates for the various ground and air transportation systems are shown in Figure 9-1.

### Construction Costs

It is difficult to estimate the cost of an HSR or maglev system in the United States because no system was actually built, and foreign experience cannot be easily translated. Furthermore, maglev systems have only been operational on test tracks and most of them remain in the prototype design stage.

There are reasons to believe that the U.S. feasibility studies based on the TGV system provide good cost estimates (ridership estimates, however, are questionable). The actual cost of the French Southeast line was no more than one percent higher than the planning cost estimated seven years earlier. Furthermore, the TGV feasibility reports contain a detailed

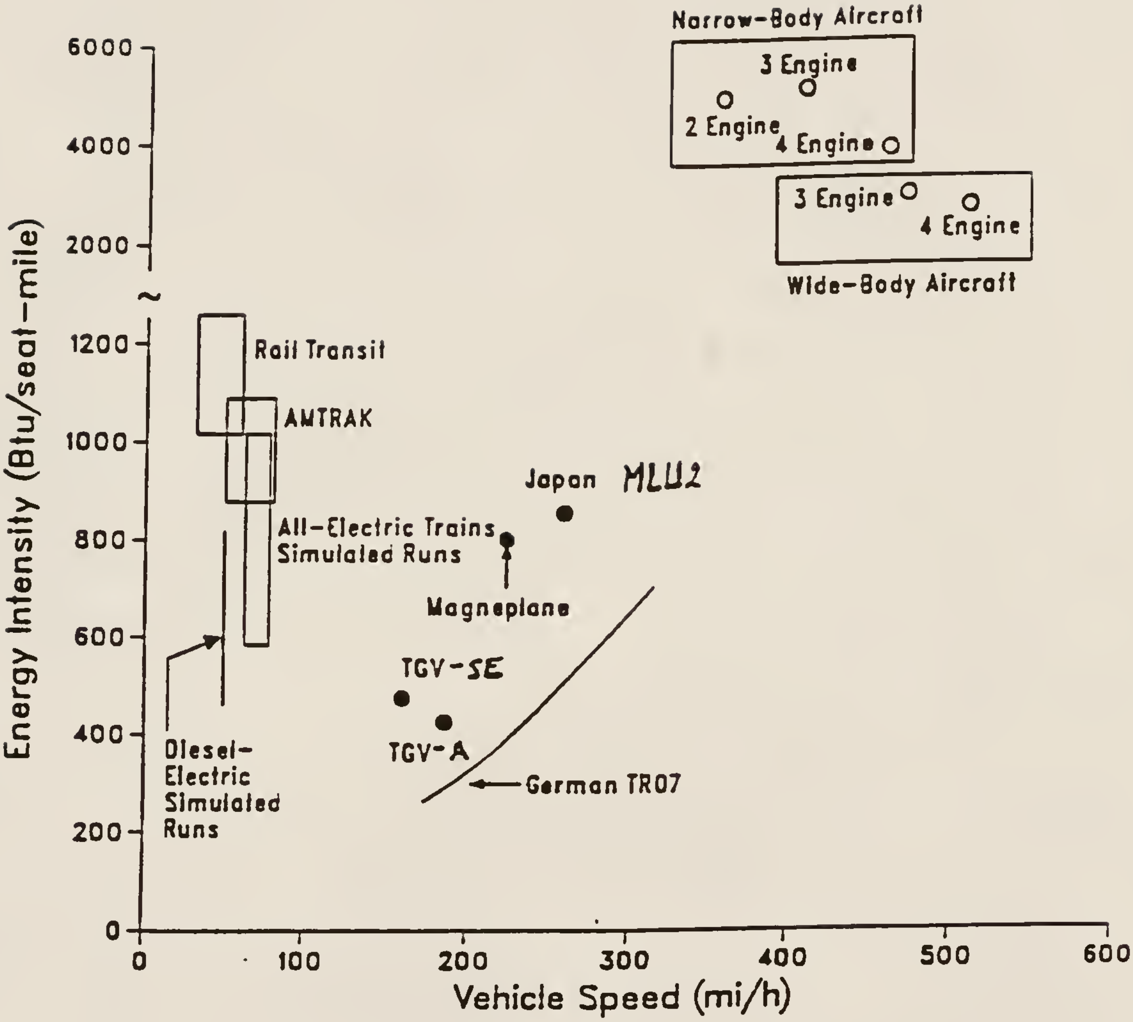
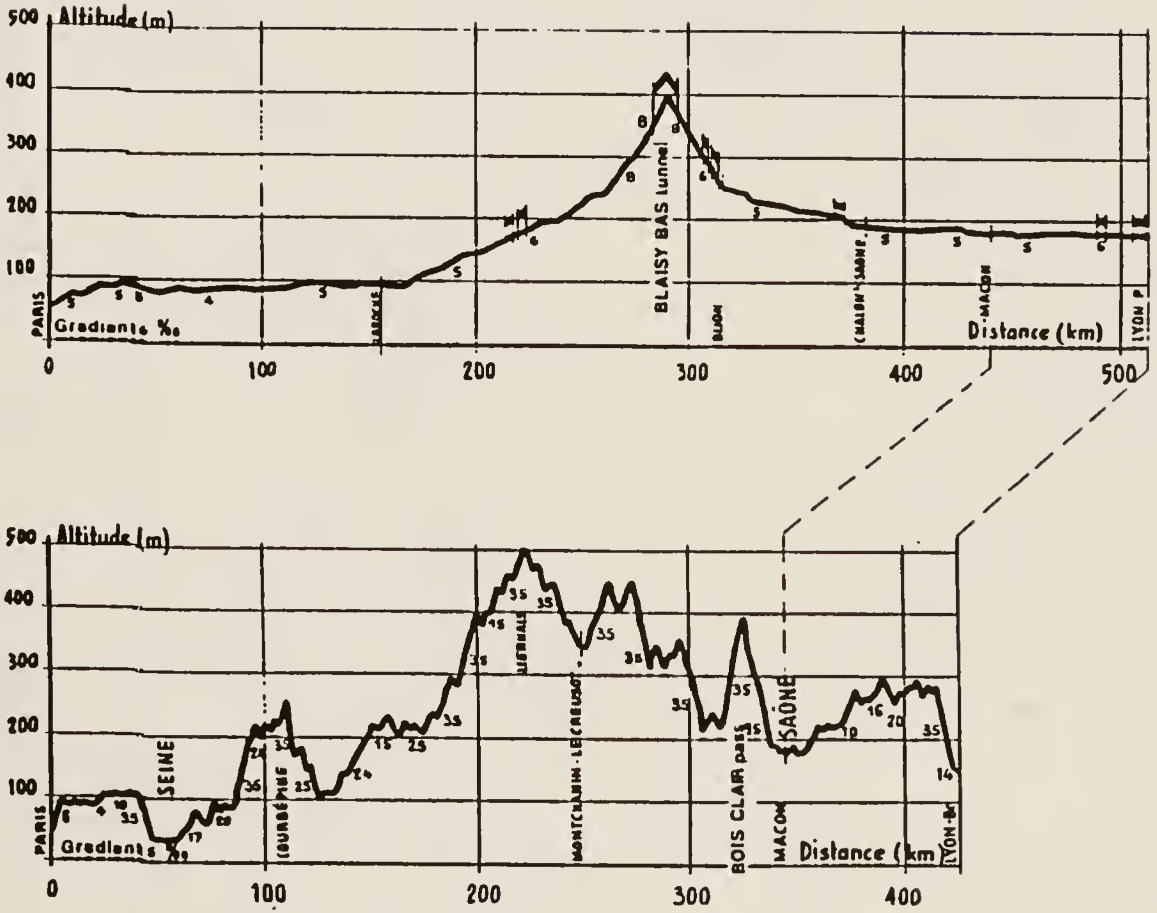


Figure 9-1: Energy Consumption Rates of Various Modes
Source: Johnson et al., 1989.

description of all the earthwork and construction activities required, as well as the various operating costs.

On the other hand, the cost estimates for maglev systems vary substantially among studies. All reports and studies indicate that a maglev system costs more than an HSR system. The cost disparity ranges from 30% to over 200%, depending on the route's location, topography and length. Preliminary cost estimates for maglev demonstration projects are very high because they include the cost of a one-year testing period required by FRA. One of the objectives of the U.S. Maglev Initiative is to develop a low cost maglev system by reducing guideway cost. The guideway structure accounts for the largest cost component. However, maglev requires additional guideway and wayside equipments that are quite expensive. Furthermore, Transrapid trainsets are more expensive than HSR trains.

In mountainous terrain, maglev systems present an advantage due to their greater climbing ability. This can be translated into significant savings in earthworks and special structures. For instance, the TGV-SE line was shorter than the old rail line because the TGV-SE can climb 2.5 % steeper grades than conventional rail. The old and new route profiles are shown in Figure 9-2. Transrapid is capable of climbing five percent steeper grades than HSR systems. Further studies are needed to fully assess the cost benefits of maglev climbing ability for various types of terrain.



Old Paris-Lyon Rail Line Profile

New Paris-Lyon Rail Line (TGV-SE)

Figure 9-2: Profiles of the Old and New Paris-Lyon Rail Lines
Source: Dupuy, 1978.

One study that compared ICE and Transrapid indicated that in flat terrain a double-track ICE system requires about 26.5 $m^2/m$ of land as compared to 23.5 $m^2/m$ for Transrapid. In hilly terrain, however, the ICE requires 45.5 $m^2/m$ of land as compared to 25 $m^2/m$ for Transrapid. In regard to earthwork, the ICE double track causes an earth displacement of 78 $m^3/m$ in Flat terrain and 195 $m^3/m$ in hilly terrain. This compares to 11.8 $m^3/m$ in flat terrain and 44.5 $m^3/m$ in hilly terrain for Transrapid (MVP, 1991). Another advantage of Transrapid is that its overpasses cost about 80% less than a HSR overpass. This is due to Transrapid's lighter trains and structure.

Finally, the study commissioned by the Transportation Research Board estimated that the cost of an HSR system varies from $10.3 to $11.1 million per km; and the cost of a maglev system varies from $16.7 to $20.1 million per km, which is about 70% higher (1991 dollars). Maglev operating costs were estimated to be about 20% lower than those of HSR systems. Chapter 2 included a detailed description of the reasons behind the cost disparity between the TGV lines implemented in France and the ICE lines implemented in Germany. The ICE lines were more than twice as expensive per mile as the TGV lines.

## Recommendations

There is a need to develop a uniform cost estimation procedure for HSR and maglev systems. This should be based on a detailed and representative coding system that includes a precise description of each item. At present, most feasibility studies use a similar terminology to describe items that are quite different. Item names such as embankment, bridge, elevated guideway, upgraded track, etc., are too general to be translated or compared with items from other studies.

The development of a detailed coding system goes a long way in helping planners and consultants produce more accurate cost estimates with lesser effort. This will be a first step in developing a unit cost database for HSR and maglev systems that can have a national usefulness. Adjustment factors can be used to adapt these costs to various locations and conditions.

The cost estimation procedure presented in this dissertation is designed to interact with a unit cost database to produce quick preliminary cost estimates. Once the unit cost database is developed, updating it in future years is a relatively easy task because the various cost components of each item would be well defined.

The study sponsored by the USDOT to develop cost estimates for 52 maglev guideway types is a step in the right direction. The cost components of each guideway type (e.g., Table 7-7) are well defined and can be easily updated and used by other studies. However, further sponsored research is needed to complete the unit cost database. This includes estimating the costs to extend or rebuild various types of highway and railroad bridges, the cost to upgrade tracks from their present classification to HSR standards, and others.

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## ABBREVIATIONS

| | |
|---|---|
| BAAI | Barton-Aschman Associates, Inc. |
| CIDEM | *Commission d'Initiative et de Developpement Economic de Montreal* |
| CIGGT | Canadian Institute of Guided Ground Transportation |
| FDOT | Florida Department of Transportation |
| FRA | Federal Railroad Administration |
| FHSRC | Florida High-Speed Rail Corporation |
| ICE | InterCity Express |
| PBQD | Parsons Brinckerhoff Quade and Douglas |
| RGCF | *Revue Generale des Chemins de Fer* |
| TRB | Transportation Research Board |
| TTA | Texas Turnpike Authority |
| USDOT | United States Department of Transportation |

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# APPENDIX A
# LISTING OF THE OPERATION SIMULATION MODEL WRITTEN IN FORTRAN

```
C
C                   HSGT OPERATIONAL SIMULATION MODEL
C                        By:  Fadi Emil Nassar
C                        University of Florida
C
C      ***************    VARIABLES    ****************
C
      REAL MM(10,0:4300),A,VI,VF,VA,VM,DDI,ENA,ENT,ENP,ENS,EX
      REAL GG(3,500),CC(6,500),ZZ(4,500),STA(2,50),ET,EU,EXT
      REAL AA(13),DD(13),ENC(0:13),DDD(13),VV(0:255),EUE,ETE
      REAL NNAA,NNBB,NNCC,EEHSR,EEAA,EEBB,EECC,EEVV,ETR,ENS2
      REAL L,S,F1,F2,F3,C4,F5,P1,P2,RR(1000,5),PERF(30,13)
      REAL ST(6),PT(6),SF,EXTRA,NEW,DECEL,DT,DTT
      INTEGER SS(6),PF,SEAT,HSGT,FL,SST
      INTEGER I,J,K,LS,SN,CN,GN,ZN,RA,RD,RF,RP,RS,Y1,LA
      CHARACTER STATUS(0:4300)*2,FNAME*25,Z(0:52)*53,SNAME*25
      CHARACTER SP(0:4300)*1,CODE(500)*1,DNAME*25
C
C                 ***************************
C       *******      VARIABLES DEFINITION      *******
C      *************************************************
C
C      MAIN MATRIX    MM(10,0:5000)  (MAX 5000 SECTIONS (I))
C
C      MM(1,I)     grades (percent) for section I
C      MM(2,I)     curve radius (m) for section I
C      MM(3,I)     track superelevation (degree)
C      MM(4,I)     section's computed speed limit (km/hr)
C      MM(5,I)     actual section's simulated speed (km/hr)
C      MM(6,I)     crossing time for section I
C      MM(7,I)     cumulative time
C      MM(8,I)     acceleration for section I (m/sec2)
C      MM(9,I)     noise emission (before: backward speed limit)
C      MM(10,I)    energy consumption for section I (KWHR)
C      SP(0:5000)*1  one-letter speed-limit code for section I
C      STATUS(0:5000)*1  one-letter acceleration code: S=stop
C                  A=accelerate, D=decelerate, C=cst speed
C
C          *******      ROUTE DATA      *******
C
C      L           route length  (km)
C      S           length of each route section  (km)
C      LS          total number of route sections
C      LA          length of the look-ahead distance  (km)
C      VI          initial trainset speed  (km/hr)
C      VF          final trainset speed  (km/hr)
C      VM          maximum design speed (km/hr)
C      VA          average speed excluding stops (km/hr)
C      RR(1000,5)  array tO stores route data from input file
C
```

```
C
C          HORIZONTAL CURVE MATRIX   CC(6,500) (MAX 500 CURVES)
C
C      CC(1,I)      starting location (km)
C      CC(2,I)      curve's length    (km)
C      CC(3,I)      curve's radius    (m)
C      CC(4,I)      curve's track superelevation  (degree)
C     CC(5,I)     exceptional allowable lateral accel. (m/sec2)
C      CC(6,I)      computed allowable speed on curve  (km/hr)
C      CN           number of curves
C      EU           typical allowable lateral accel.  (m/sec2)
C     EUE         exceptional allowable lateral accel. (m/sec2)
C      EX           actual allowable lateral accel.  (m/sec2)
C      ETR          typical track superelevation  (degree)
C      ETE          exceptional track superelevation  (degree)
C      EXT          actual track superelevation  (degree)
C      ET           effective trainset tilt -- if any  (degree)
C
C           GRADE MATRIX   GG(3,500)   (MAX 500 GRADE SEGMENTS)
C
C      GG(1,I)      starting location of grade segment I  (km)
C      GG(2,I)      length of grade segment I (km)
C      GG(3,I)      grade  (percent)
C      GN           number of grade segments
C
C         SPEED RESTRICTION ZONES   ZZ(4,500)   (MAX 500 ZONES)
C
C      ZZ(1,I)      starting location of speed restriction zone
C      ZZ(2,I)      speed reatriction zone's length  (km)
C      ZZ(3,I)      imposed speed limit  (km/hr)
C     ZZ(4,I)     number corresponding to 1 alphabet code (1-26)
C      ZN           number of speed restriction zones
C     CODE(500)*1  alphabet-code describing the speed-limit zone
C                      ex:  B=bridge, O=overpass, T=tunnel, etc.
C
C          STATIONS       STA(2,50)      (MAX 50 STATIONS)
C
C      STA(1,I)     station's location  (km)
C      STA(2,I)     dwelling time for station I (min)
C      SN           number of intermediate stations
C      DT           average dwelling time per station (min)
C      DTT          total dwelling times for stations
C
C          ******     TECHNOLOGY RELATED VARIABLES     ******
C
C      PF        selection of technology from menu
C     HSGT     type of HSGT system (Transrapid=1, TGV=2, ICE=3)
C      SST       number of all sections in a trainset
C      SEAT      number of seats in trainset (input/system file)
C     PERF()    stores performance data for default HSGT systems
C      AA(13)    acceleration rates (file) per speed increment
```

```
C      DD(13)    deceleration rates (file) per speed increment
C      DDD(13)   input deceleration rates (interactive)
C      DDI       constant deceleration rate
C      DECEL     recommended deceleration rate from system file
C      VV(255)   speed per section for the look-ahead distance
C      Z(52)     store graphical outputs for speed profile
C      EXTRA     percent grade overcome by extra tractive power
C
C                     ENERGY CONSUMPTION
C            MODELING EQUATION FORM = (a x2 + b x + c)
C
C     EEAA      energy consumption 'a' coef in modeling equation
C     EEBB      energy consumption 'b' coef in modeling equation
C     EECC      energy consumption 'c' coef in modeling equation
C     EEVV     average section speed used for energy consumption
C     EEHSR     energy consumption coefficient for TGV,ICE,XT200
C      ENC(13)   energy consumption per speed increment (file)
C      ENS       calculated energy consumption per section (KWH)
C      ENS2      energy consumption adjusted for grades (KWH)
C      ENT       total enery consumption (KWH)
C      ENA       average energy consumption per km (KWH/KM)
C      ENP       average energy consumption per passenger-km
C
C                   NOISE EMISSION  (AT 25 METERS)
C            MODELING EQUATION FORM = (a x2 + b x + c)
C
C      NNAA      noise emission 'a' coef in modeling equation
C      NNBB      noise emission 'b' coef in modeling equation
C      NNCC      noise emission 'c' coef in modeling equation
C
C
C           *******    COEFFICIENTS AND PARAMETERS   *******
C
C      F1        unit conversion factor (F1=12960)
C      F2        unit conversion factor (F2=216)
C      F3        unit conversion factor (F3=60)
C     C4        translates superelevation from degree to radiant
C      F5        translates degree of curve to radius in feet
C      SF        value used in internal calculations (=100xS)
C      A         value used for acceleration rate
C     P1       value used in calculations (=sqare initial speed)
C      P2        value used in internal calculations (=2xAxSxF1)
C      Y1        integer used in calculations (=INT(speed/10))
C      NEW       computed adjusted acceleration
C      SS(6)     sections per speed increment of 100 km/hr
C     ST(6)    cumulative travel time per increment of 100 km/hr
C     PT(6)    percentage travel time per increment of 100 km/hr
C      I,J,K     used in Do Loop
C     RD,RS,RF,FL,RP,RA store user's choice in interactive input
C
C
```

```
C              ******     INPUT FILES     ******
C
C      FNAME*25   variable to store simulation output filename
C     SNAME*25   variable to store speed profile output filename
C      DNAME*25   variable to store route data filename
C      SYSTEMS    file containing default HSGT performance data
C
C
****************************************************************
C
C     ******    READ PERFORMANCE DATA FROM FILE (PERF)   *******
C
      OPEN (UNIT=3, FILE='SYSTEMS',STATUS='OLD',
     +         ACCESS='SEQUENTIAL', FORM='FORMATTED')
      DO 42 I=1,28
             READ (UNIT=3,FMT=44) (PERF(I,J), J=1,12)
C             PRINT 44, (PERF(I,J), J=1,12)
  42  CONTINUE
  44  FORMAT (10F7.3,F6.1,F4.2)
       CLOSE (3)
C
C        ************    SELECT HSGT SYSTEM    *************
C
  43  PRINT*
      PRINT*,'Select one of the following HSGT systems:'
      PRINT*
      PRINT*,' <1>   User Defined HSR or Maglev System.'
      PRINT*,' <2>   MAGLEV - TRANSRAPID 07   (1P+ 0T+1P)'
      PRINT*,' <3>   MAGLEV - TRANSRAPID 07   (1P+ 1T+1P)'
      PRINT*,' <4>   MAGLEV - TRANSRAPID 07   (1P+ 2T+1P)'
      PRINT*,' <5>   MAGLEV - TRANSRAPID 07   (1P+ 3T+1P)'
      PRINT*,' <6>   MAGLEV - TRANSRAPID 07   (1P+ 4T+1P)'
      PRINT*,' <7>   MAGLEV - TRANSRAPID 07   (1P+ 5T+1P)'
      PRINT*,' <8>   MAGLEV - TRANSRAPID 07   (1P+ 6T+1P)'
      PRINT*,' <9>   MAGLEV - TRANSRAPID 07   (1P+ 7T+1P)'
      PRINT*,' <10>  MAGLEV - TRANSRAPID 07   (1P+ 8T+1P)'
      PRINT*,' <11>  HSR  - TGV-N             (1P+ 8T+1P)'
      PRINT*,' <12>  HSR  - TGV-A             (1P+10T+1P)'
      PRINT*,' <13>  HSR  - ICE               (1P+12T+1P)'
      PRINT*,' <14>  HSR  - X-2000            (1P+5T)'
      PRINT*,' <15>  HSR  - X-2000            (1P+6T)'
      PRINT*
      READ*,PF
C
C              ***   ADJUST (PF.GT.15) FOR ADDED SYSTEM
       IF (PF.GT.15) GOTO 43
C
       SEAT=0
       EXTRA=0
       DTT=0
       DT=0
       NNAA=0
```

```
        NNBB=0
        NNCC=0
        EEAA=0
        EEBB=0
        EECC=0
        ENS=0
        ENP=0
        ENT=0
C
        IF (PF.EQ.1) THEN
          PRINT*
          PRINT*,'Enter the Maximum Design Speed (km/hr):'
          READ*, VM
          PRINT*
          PRINT*,'Enter Acceleration & Deceleration Rates ',
     +          'per speed increments of 50 km/hr:'
          DO 227 I=1,1+INT(VM/50)
            PRINT*
            PRINT 229, 50*(I-1),50*I
            READ*, AA(I),DDD(I)
            DD(I)=-DDD(I)
  227     CONTINUE
  229       FORMAT('Enter Accel. & positive Decel.',
     +          ' rates (m/s2) for:',I4,' to',I4,' km/hr?')
          GOTO 14
        ENDIF
C
C      ***   TRANSRAPID DEFAULTS FOR ENERGY CONSUMPTION   ***
        IF (PF.LT.11.AND.PF.GT.1) THEN
            EXTRA=.25
            HSGT=1
C      ***   TRANSRAPID NOISE MODELING COEFFICIENTS   ***
            NNAA=56.092
            NNBB=0.1284
            NNCC=-.00008774
C         ***   TRANSRAPID ENERGY COEFFICIENT  ***
            EEAA=PERF(PF*2-2,1)/10
            EEBB=PERF(PF*2-2,2)/1000
            EECC=PERF(PF*2-2,3)/100000
CC         ENC(0)=ENC(1)
        ENDIF
C
C      ***   TGV  DEFAULTS FOR ENERGY CONSUMPTION  ***
        IF (PF.EQ.11.OR.PF.EQ.12) THEN
            EXTRA=0.
            HSGT=2
            EEHSR=PERF(PF*2-2,1)
        ENDIF
C
C      ***   ICE  DEFAULTS FOR ENERGY CONSUMPTION  ***
        IF (PF.EQ.13) THEN
            EXTRA=0.
            HSGT=3
            EEHSR=PERF(PF*2-2,1)
        ENDIF
C
C      ***   X-2000  DEFAULTS FOR ENERGY CONSUMPTION  ***
        IF (PF.EQ.14.OR.PF.EQ.15) THEN
            EXTRA=0.
            HSGT=4
            EEHSR=PERF(PF*2-2,1)
        ENDIF
C
C
        DO 47 I=1,10
            AA(I)= PERF(PF*2-3,I)
cc            ENC IS 10 INCREMENTS OF ENERGY CONSUMPTION RATES
cc            ENC(I)= PERF(PF*2-2,I)
 47     CONTINUE
C
        SEAT= INT(PERF(PF*2-2,11))
C         ***   ENERGY MODELING COEFFICIENT    ***
C         ***   NO VALUES AVAILABLE YET FOR TGV AND ICE   ***
  39    PRINT*
C
       DECEL = PERF(PF*2-3,12)
       SST = INT(PERF(PF*2-2,10))
C
C        *************    INPUT ROUTE DATA    ****************
C
 14    PRINT*
       PRINT*,'Enter the Length of the HSGT route (km):'
       READ*,L
C
C        ********   If L=0, PRINT A SPEED-DISTANCE PROFILE
C
          IF (NINT(L).EQ.0) THEN
             L=50.
             S=.5
             VM=INT(PERF(PF*2-3,11))
             VI=0.
             VF=0.
             STATUS(0)='A'
             LS=INT(L/S+1)
             SN=0
             PRINT*
             PRINT 48, -DECEL
             READ*, RA
             IF (RA.EQ.1) THEN
               DDI=DECEL
               PRINT*
             ELSE
               PRINT*
               PRINT*,'Enter the comfortable Deceleration Rate ',
     +            'as a positive value (m/s2):'
                 READ*, DDI
               ENDIF
               DO 223 I=1,11
                  DD(I) = -DDI
 223           CONTINUE
               DD(1)=DD(3)*3/4
          DO 711 I=0,LS+50
             DO 722 J=1,10
                MM(J,I)=0.
             MM(4,I)=VM
             SP(I)=' '
  722        CONTINUE
 711      CONTINUE
               MM(4,LS-1)=VF
               DO 269 I=1,6
                  SS(I)=0
                  ST(I)=0
 269           CONTINUE
               GOTO 334
            ENDIF
C
         PRINT*
         PRINT*,'Enter the Length of each route section (km):'
         READ*,S
         PRINT*
         IF (PF.GT.1) THEN
           PRINT*,'  ****** Maximum speed of selected system is:',
     +     INT(PERF(PF*2-3,11)),'  km/hr  ******'
           PRINT*
           PRINT*,'Enter the Maximum Design Speed (km/hr):'
           READ*, VM
           PRINT*
         ENDIF
         PRINT*,'Enter Initial and Final Speeds (km/hr):'
         READ*, VI,VF
         LS = INT(L/S+1)
         PRINT*
C
         IF (PF.EQ.1) GOTO 228
C
         PRINT 48, -DECEL
  48     FORMAT ('Do you want to use default',
     +        ' Deceleration Rate of:',F6.2,' m/s2 (1=Yes/0=No)')
         READ*, RA
         IF (RA.EQ.1) THEN
           DDI=DECEL
           PRINT*
           DO 49 I=1,11
             DD(I) = -DDI
 49        CONTINUE
             DD(1)=DD(3)*3/4
         GOTO  228
       ENDIF
C
       PRINT*
       PRINT*,'Is Comfortable Deceleration Rate Constant ',
     +        '(1=Yes/0=No)?'
       READ*, RA
       PRINT*
       IF (RA.EQ.1) THEN
         PRINT*,'Enter the comfortable Deceleration Rate ',
     +          'as a positive value (m/s2):'
         READ*, DDI
         DO 224 I=1,11
           DD(I)  = -DDI
 224     CONTINUE
           DD(1)=DD(3)*3/4
       ELSE
         PRINT*,'Enter Deceleration Rates ',
     +          'per speed increments of 50 km/hr:'
         DO 225 I=1,1+INT(VM/50)
           PRINT 226,50*(I-1),50*I
  226      FORMAT('Enter positive deceleration rate (m/s2) for:'
     +           ,I4,' to',I4,' km/hr?')
           READ*, DDD(I)
           DD(I)=-DDD(I)
  225    CONTINUE
       ENDIF
C
  228  IF (VI.LT.1.) THEN
               STATUS(0)='A'
       ENDIF
C
C      ***************    INITIALIZE MATRIX  **************
C
        DO 100 I=0,LS+50
           DO 101 J=1,10
              MM(J,I)=0.
           MM(4,I)=VM
           SP(I)=' '
  101      CONTINUE
 100    CONTINUE
C
       DO 268 I=1,6
          SS(I)=0
          ST(I)=0
 268   CONTINUE
C
       DO 34 I=1,1000
         DO 35 J=1,5
            RR(1000,J)=0
 35      CONTINUE
 34    CONTINUE
```

```
C
      MM(4,LS-1)=VF
C
C     ******************************************************
C                    ROUTE DATA INPUT FILE
C
      PRINT*,'Do you want to enter route data using',
     +       ' keyboard or input file (1=keyb/2=File)'
      READ*, FL
C
        PRINT*
C
      IF (FL.EQ.2) THEN
        PRINT*
        PRINT*
        PRINT*,'Enter the number of intermediate stations:'
        READ*,SN
        PRINT*
        PRINT*,'Enter the number of grade segments:'
        READ*,GN
        PRINT*
        PRINT*,'Enter the number of horizontal curves:'
        READ*,CN
        PRINT*
        PRINT*,'Enter the number speed-restriction segments:'
        READ*,ZN
        PRINT*
C
        PRINT*,'Enter File Name   ',
     +   '((Name and Directory must be inside single quotes)):'
        READ*,DNAME
        PRINT*
C
        OPEN (UNIT=4, FILE=DNAME, STATUS='OLD',
     +         ACCESS='SEQUENTIAL', FORM='FORMATTED')
        DO 36 I=1,SN+GN+CN+ZN
             READ (UNIT=4,FMT=37) (RR(I,J), J=1,5)
             IF (I-1.EQ.0.AND.SN.GT.0) THEN
                   PRINT*
                   PRINT*, '        STATIONS'
             ENDIF
             IF (I-1.EQ.SN.AND.GN.GT.0) THEN
                   PRINT*
                   PRINT*, '        GRADES'
             ENDIF
             IF (I-1.EQ.SN+GN.AND.CN.GT.0) THEN
                   PRINT*
                   PRINT*, '        CURVES'
             ENDIF
             IF (I-1.EQ.SN+GN+CN.AND.ZN.GT.0) THEN
                   PRINT*
                   PRINT*, '        SPEED RESTRICTIONS'
```

```
              ENDIF
              PRINT 37, (RR(I,J), J=1,5)
   36      CONTINUE
   37      FORMAT (F13.3,4F10.3)
           CLOSE (4)
C
         IF (CN.GT.0.) THEN
           PRINT*
           PRINT*,'Enter Typical Allowable Lateral',
     +            ' Acceleration (m/s2) :'
           READ*,EU
           PRINT*
           PRINT*,'Enter Exceptional Allowable Lateral',
     +            ' Acceleration (m/s2) :'
           READ*,EUE
           PRINT*
           PRINT*,'Enter Typical Track Superelevation (degree) :'
           READ*,ETR
           PRINT*
          PRINT*,'Enter Exceptional Track Superelevation (degree):'
           READ*,ETE
           PRINT*
           PRINT*,'Enter Maximum Effective Train Tilt (degree) :'
           READ*,ET
         ENDIF
C
           DO 61 I=1,SN
              STA(1,I) = RR(I,1)
              STA(2,I) = RR(I,2)
   61      CONTINUE
C
           DO 62 I=1,GN
              J=I+SN
              GG(1,I) = RR(J,1)
              GG(2,I) = RR(J,2)
              GG(3,I) = RR(J,3)
   62      CONTINUE
C
           DO 63 I=1,CN
             J=I+SN+GN
              CC(1,I) = RR(J,1)
              CC(2,I) = RR(J,2)
              CC(3,I) = RR(J,3)
              CC(4,I) = RR(J,4)
                IF (NINT(CC(4,I)).EQ.0) THEN
                     EXT=ETR
                ELSE
                     IF (NINT(CC(4,I)).EQ.-1) THEN
                         EXT=ETE
                     ELSE
                         EXT=CC(4,I)
                     ENDIF
```

```
               ENDIF
             CC(5,I) = RR(J,5)
               IF (NINT(CC(5,I)).EQ.0) THEN
                    EX=EU
               ELSE
                    IF (NINT(CC(5,I)).EQ.-1) THEN
                        EX=EUE
                    ELSE
                        EX=CC(5,I)
                    ENDIF
               ENDIF
            C4=0.017453*(EXT+ET)
            CC(6,I)=3.6*SQRT(CC(3,I)*(EX+9.81*SIN(C4))/COS(C4))
  63     CONTINUE
C
         DO 64 I=1,ZN
            J=I+SN+GN+CN
            ZZ(1,I) = RR(J,1)
            ZZ(2,I) = RR(J,2)
            ZZ(3,I) = RR(J,3)
            ZZ(4,I) = RR(J,4)
  64     CONTINUE
C
          GOTO 31
       ENDIF
C
C        *************************************************
C               ********   READ GRADE DATA   *********
C
        PRINT*
        PRINT*,'Enter the number of intermediate stations:'
        READ*,SN
        DO 114 I=1,SN
          PRINT*
          PRINT*,'Enter for Station no.:',I
          PRINT*
          PRINT*,'Location (km), and Dwelling Time (minutes):'
          READ*,STA(1,I),STA(2,I)
          PRINT*
 114    CONTINUE
        PRINT*
        PRINT*,'Enter the number of Grade Segments:'
        READ*,GN
        DO 118 I=1,GN
          PRINT*
          PRINT*,'Enter for grade segment no.:',I
          PRINT*
          PRINT*,'Starting post (km), Length (km),',
     +          'and Grade (%):'
          READ*,GG(1,I),GG(2,I),GG(3,I)
          PRINT*
 118    CONTINUE
```

```
      PRINT*
C
C       ***********   READ HORIZONTAL CURVE DATA   **********
C
      PRINT*,'Enter the number of Horizontal Curves:'
      READ*,CN
      IF (CN.EQ.0) GOTO 131
      PRINT*
C            ***** TILT IN DEGREE IS   "ET"
      PRINT*,'Enter allowable Lateral Acceleration (m/s2) and',
     +        ' Train Tilt (degree) :'
      READ*,EU,ET
C
      DO 128 I=1,CN
         PRINT*
         PRINT*,'Enter for Curve:',I
         PRINT*,'Starting point (km), Length (km), Radius (m),',
     +         ' and track Superelevation (degree)'
         READ*,CC(1,I),CC(2,I),CC(3,I),CC(4,I)
         C4=2*3.1416/360.*(CC(4,I)+ET)
         CC(6,I)=3.6*SQRT(CC(3,I)*(EU+9.81*SIN(C4))/COS(C4))
         PRINT*
         PRINT*,'  **  ALLOWABLE SPEED ON CURVE:',I,'      IS:',
     +          INT(CC(6,I)),'  km/hr'
         PRINT*
 128  CONTINUE
      PRINT*
C
C      ********   READ SPEED RESTRICTION ZONES DATA   *********
C
 131  PRINT*
      PRINT*,'Enter the number of Speed Restriction Zones:'
      READ*,ZN
      DO 133 I=1,ZN
        PRINT*
        PRINT*,'Enter for Speed Restriction Zone no.:',I
        PRINT*
        PRINT*,'Starting Point (km), Length (km), Allowable ',
     + 'Speed (km/hr) and one letter Code:'
       PRINT*,'** THE LETTER CODE SHOULD BE IN SINGLE QUOTES **'
       PRINT*,'(Ex: B for Bridge, O for overpass, T for Tunnel)'
        READ*,ZZ(1,I),ZZ(2,I),ZZ(3,I),CODE(I)
       PRINT*
      PRINT*
 133  CONTINUE
  31   PRINT*
C                ******************************
C
C      *****  READ GRADE DATA TO MAIN MATRIX ****
C
      DO 115 I=1,GN
         DO 116 J=INT(GG(1,I)/S), INT((GG(1,I)+GG(2,I))/S)
```

```
          MM(1,J)=GG(3,I)
 116    CONTINUE
115   CONTINUE
C
C     ******  COMPUTE MAXIMUM ALLOWABLE SPEED ON CURVES  ****
C
      DO 140 I=1,CN
         DO 160 J=INT(CC(1,I)/S), INT((CC(1,I)+CC(2,I))/S)
           MM(2,J)=CC(3,I)
           MM(3,J)=CC(4,I)
           MM(4,J)=MIN(CC(6,I),VM)
           SP(J)='C'
 160    CONTINUE
 140  CONTINUE
C
C     *****  READ SPEED RESTRICTION DATA TO MAIN MATRIX  *****
C
      DO 138 I=1,ZN
        DO 139 J=INT(ZZ(1,I)/S), INT((ZZ(1,I)+ZZ(2,I))/S)
           IF (MM(4,J).GT.ZZ(3,I)) THEN
               MM(4,J)=ZZ(3,I)
               IF (FL.EQ.1) THEN
                  SP(J)=CODE(I)
               ELSE
                  IF (NINT(ZZ(4,I)).EQ.0) THEN
                      SP(J)='R'
                  ELSE
                      SP(J)=CHAR(NINT(ZZ(4,I)+64))
                  ENDIF
               ENDIF
           ENDIF
 139    CONTINUE
 138  CONTINUE
C
C     ******    RE-INITIALIZE MATRIX SECTIONS
C
     DO 103 I=0,LS+50
         MM(6,I)=0.
 103  CONTINUE
C
C
 334  PRINT*
C
C      ****   STATIONS DWELLING TIME
C                DTT   IS TOTAL DWELLING TIME
C                DT    IS AVERAGE DWELLING TIME
C
      DO 97 I=1,SN
         MM(4,INT(STA(1,I)/S))=0
         DTT=DTT+STA(2,I)
  97  CONTINUE
      IF (SN.GE.1) THEN
```

```
         DT=DTT/SN
      ELSE
         DT=0
      ENDIF
C
 332  PRINT*
C
C                   ********   FACTORS
      F1=12960.
      F2=216.
      F3=60.
      LA=0
C
C                   ********   CREATE DECELERATION TABLE
C
      DO 750 I=1,INT(25/S)
          VV(0)=VM
          A=DD(INT(VV(I-1)/50)+1)
          P1=VV(I-1)**2
          P2=(2*A*S*F1)
          IF (P1+P2.LE.0.00) THEN
             VV(I)=0.00
          ELSE
            VV(I)=SQRT(P1+P2)
          ENDIF
          IF (VV(I).GT.0.1) THEN
            LA=LA+1
          ENDIF
 750   CONTINUE
          PRINT*,'        LOOK AHEAD :',LA*S,' KM'
      MM(5,0)=VI
      IF (VI.LT..001) THEN
          STATUS(0)='S'
          SP(0)='S'
          MM(4,0)=0
      ENDIF
C
C
C                 ************************************
C              ***  DEVELOP BACKWARD SPEED DUMMIES  ***
C     ********************************************************
C
       DO 70 I=0,LS+1
         MM(9,I)=MM(4,I)
  70   CONTINUE
C
       MM(9,LS-1)=VF
       DO 72 K=0,LS-2
            I=LS-1-K
            IF(NINT(MM(9,I)-VM).EQ.0)  GOTO 72
            IF(NINT(MM(9,I)-MM(4,I-1)).EQ.0) THEN
               MM(9,I-1)=MM(9,I)
```

```
                GOTO 72
             ENDIF
C
           DO 73 J=0,LA
               IF (I-J.LE.1) GOTO 73
               IF (NINT(MM(9,I-J)-VM).EQ.0) GOTO 73
          NEW=SQRT(MM(9,I-J)**2-(2*DD(INT(MM(9,I-J)/50)+1)*S*F1))
               MM(9,I-J-1)=MIN(MM(9,I-J-1),NEW)
   73      CONTINUE
C
  72    CONTINUE
C
C                  ******    SIMULATION    *****
C       *******************************************************
C
       MM(5,0)=VI
       DO 78 I=1,LS
C
C                      ****  STOP  ****
C       PRINT*,I
         IF (MM(9,I).LT.0.1) THEN
                STATUS(I)='S'
                MM(5,I)=0
                A=(-MM(5,I-1)**2)/(2*S*F1)
                MM(6,I)=ABS((MM(5,I)-MM(5,I-1))/(A*F2))
                MM(8,I)=A
                GOTO 77
         ENDIF
C
C       *******************************************************
C                     ****  CST SPEED  ****
C
         IF (NINT(MM(9,I)-MM(5,I-1)).EQ.0) THEN
                STATUS(I)='C'
                MM(5,I)=MM(9,I)
                A=0
C
C                   ***   ADJUST CST SPEED FOR GRADES   ***
C
           CGA=AA(INT((MM(5,I-1)-1)/50)+1)+EXTRA-0.098*MM(1,I-1)
               IF (CGA.LT.0.001) THEN
                    A=CGA
                    STATUS(I)='D'
                    P1=MM(5,I-1)**2
                    P2=(2*A*S*F1)
C           PRINT*,'I:',I,' P1:',P1,' P2:',P2,' A:',A
                    IF (P1+P2.LT.0.0) THEN
                         MM(5,I)=0
C
C                      *** WARN OF EXCESSIVE GRADE    ****
C
       IF (MM(5,I-1).LT.0.001.AND.MM(4,I-1).GT.1.) THEN
       PRINT*,'** Excessive Grade, Reduce Slope at:',I*S,' km **'
       ENDIF
C
                        A=(-MM(5,I-1)**2)/(2*S*F1)
                        MM(8,I)=A
                        MM(6,I)=ABS((MM(5,I)-MM(5,I-1))/(A*F2))
                        GOTO 77
                      ELSE
                        MM(5,I)=SQRT(P1+P2)
                        MM(8,I)=A
                        MM(6,I)=ABS((MM(5,I)-MM(5,I-1))/(A*F2))
                        GOTO 77
                      ENDIF
               ENDIF
               MM(6,I)=F3*S/ABS(MM(5,I))
               MM(8,I)=A
               GOTO 77
        ENDIF
C
C      ********************************************************
C                 ****  DECELERATION  ****
C
         IF  ((MM(9,I)-MM(5,I-1)).LT.0.1) THEN
                STATUS(I)='D'
                MM(5,I)=MM(9,I)
                A=((MM(5,I)**2-MM(5,I-1)**2)/(2*S*F1))
                MM(8,I)=A
                MM(6,I)=ABS((MM(5,I)-MM(5,I-1))/(A*F2))
                GOTO 77
         ENDIF
C
C      ********************************************************
C                 ****   ACCELERATION  *****
C
         IF  ((MM(9,I)-MM(5,I-1)).GT.0.1) THEN
                STATUS(I)='A'
                A=AA(INT((MM(5,I-1)-1)/50)+1)
C
C                 ***   ADJUST ACCELERATION FOR GRADES  ***
C
               IF (MM(1,I-1).LT.-0.01) THEN
C    A=MIN((A-(0.098*MM(1,I-1))),AA(((INT(MM(5,I-1)-1)/50)+1)))
           A=MIN((A-(0.098*MM(1,I-1))),AA(1))
               ENDIF
C
               IF (MM(1,I-1).GT.0.01) THEN
                 A=A-(0.098*MM(1,I-1))+EXTRA
                  IF (A.LT.0.0001) THEN
                       STATUS (I)='D'
                       P1=MM(5,I-1)**2
                       P2=(2*A*S*F1)
C           PRINT*,'I:',I,' P1:',P1,' P2:',P2,' A:',A
```

```
                     IF (P1+P2.LT.0.0) THEN
                         MM(5,I)=0
C
C                 ***   WARN OF EXCESSIVE GRADE   ****
C
       IF (MM(5,I-1).LT.0.001.AND.MM(4,I-1).GT.1.) THEN
       PRINT*,'** Excessive Grade, Reduce Slope at:',I*S,' km **'
       ENDIF
C
                         A=(-MM(5,I-1)**2)/(2*S*F1)
                         GOTO 33
                     ELSE
                          MM(5,I)=SQRT(P1+P2)
                          GOTO 33
                     ENDIF
                  ENDIF
               ENDIF
C
               P1=MM(5,I-1)**2
               P2=(2*A*S*F1)
               MM(5,I)=SQRT(P1+P2)
C
C        ****** ADJUST TRANSITION SPEED/COMPUTE NEW ACCELERATION
C
  33       IF (MM(5,I).GT.MM(9,I)) THEN
                MM(5,I)=MM(9,I)
                A=((MM(5,I)**2-MM(5,I-1)**2)/(2*S*F1))
C                 PRINT*,'I=',I,'A=',A
           ENDIF
C           IF ((MM(5,I)-MM(5,I-1)).LT.0.01) THEN
C                  MM(6,I)=F3*S/ABS(MM(5,I))
C                  MM(8,I)=0.
C                  STATUS(I)='C'
C                  GOTO 129
C           ENDIF
            IF (MM(5,I).LT.MM(5,I-1)) THEN
                  A=((MM(5,I)**2-MM(5,I-1)**2)/(2*S*F1))
                  STATUS(I)='D'
           ENDIF
C               PRINT*,'I: ',I,'   A: ',A
               IF((A.LE.0.).AND.(MM(5,I-1).LT.0.1)) THEN
       PRINT*,'** Excessive Grade, Reduce Slope at:',I*S,' km **'
            ENDIF
               MM(8,I)=A
               MM(6,I)=ABS((MM(5,I)-MM(5,I-1))/(A*F2))
 129    ENDIF
C
C              ******   COMPUTE ENERGY CONSUMPTION
C
C   77         IF (PF.EQ.1) GOTO 78
CC         ENS=ENC(INT((MM(5,I-1)+MM(5,I))/100)+1)*S
  77      EEVV=(MM(5,I-1)+MM(5,I))/2
```

```
C
C      **  ENERGY CONSUMPTION COEFFICIENTS FOR HSR  **
        IF (PF.GT.10) THEN
          ENS=EEHSR*S
          GOTO 21
        ENDIF
C
          ENS=(EEAA+(EEBB*EEVV)+(EECC*EEVV*EEVV))*S
C
C             *****  ADJUST ENERGY CONSUMPTION FOR GRADES
C
           IF (MM(1,I).GT.0.5) THEN
             ENS2=MIN(0.15,0.05*MM(1,I))
             ENS=ENS*(1+ENS2)
           ENDIF
C          PRINT 636,EEVV,EEAA,EEBB,EECC,ENS/S
C 636    FORMAT('V:',F9.2,' a:',F7.3,' b:',F9.6,' c:',F11.8,
C     +         ' EN:',F6.2)
  21      MM(10,I) =  MM(10,I-1)+ENS
  78    CONTINUE
C
        ENT=MM(10,LS-1)
        ENA=ENT/L
        IF(SEAT.GT.1) THEN
           ENP=ENA/SEAT
        ELSE
           ENP=0
        ENDIF
C
 495   IF (MM(5,1).GT.MM(5,0)) THEN
             STATUS(0) = 'A'
             MM(8,0)=((MM(5,1)**2-MM(5,0)**2)/(2*S*F1))
        ELSE
           IF (MM(5,1).LT.MM(5,0)) THEN
                STATUS(0) = 'D'
                MM(8,0)=((MM(5,1)**2-MM(5,0)**2)/(2*S*F1))
           ELSE
                STATUS(0) = 'C'
                MM(8,0)=0
           ENDIF
        ENDIF
C
C       *******   ADD STATIONS' DWELLING TIMES
C
       DO 96 I=1,SN
          MM(6,INT(STA(1,I)/S))=MM(6,INT(STA(1,I)/S))+STA(2,I)
  96   CONTINUE
C
C       ****   CUMULATIVE TRAVEL TIME  AND  NOISE EMMISSION  ***
C
        MM(9,0)=NNAA
        DO 158 I=1,LS
```

```
           MM(9,I)=NNAA+NNBB*MM(5,I)+NNCC*MM(5,I)*MM(5,I)
           MM(7,I)=(MM(7,I-1)+MM(6,I))
 158    CONTINUE
C
       PRINT*
       PRINT*,'***   THE SIMULATION IS COMPLETED   ***'
       PRINT*
C
C      *******************************************************
C                   ******   OUTPUT   *******
C
C                ******   SUMMARIZE DATA   *****
C
       DO 620 I=1,LS-1
         IF (ABS(VM-MM(5,I)).LT.1.0) THEN
             SS(6)=SS(6)+1
             ST(6)=ST(6)+MM(6,I)
         ENDIF
         IF (NINT(MM(5,I)).LE.100) THEN
             SS(1)=SS(1)+1
             ST(1)=ST(1)+MM(6,I)
         ENDIF
         IF (NINT(MM(5,I)).LE.200.AND.NINT(MM(5,I)).GT.100) THEN
             SS(2)=SS(2)+1
             ST(2)=ST(2)+MM(6,I)
         ENDIF
         IF (NINT(MM(5,I)).LE.300.AND.NINT(MM(5,I)).GT.200) THEN
             SS(3)=SS(3)+1
             ST(3)=ST(3)+MM(6,I)
         ENDIF
         IF (NINT(MM(5,I)).LE.400.AND.NINT(MM(5,I)).GT.300) THEN
            SS(4)=SS(4)+1
             ST(4)=ST(4)+MM(6,I)
         ENDIF
         IF (NINT(MM(5,I)).LE.500.AND.NINT(MM(5,I)).GT.400) THEN
             SS(5)=SS(5)+1
             ST(5)=ST(5)+MM(6,I)
         ENDIF
 620   CONTINUE
       PRINT*,'   Do you want results shown on Screen      <1>'
       PRINT*,'                  stored in ASCII File      <2>'
       PRINT*,'                          or Continue?      <3>'
       READ*,RP
C       RP=3
       PRINT*
       IF (RP.EQ.1.OR.RP.EQ.2) THEN
         PRINT 171
         PRINT 172
         PRINT 82
 82       FORMAT(78('-'))
        DO 710 I=0,LS-1
          PRINT 520,I*S,STATUS(I),MM(5,I),
     +    MM(4,I),MM(6,I),MM(7,I),MM(8,I),MM(10,I),MM(9,I)
 710   CONTINUE
         PRINT 82
         PRINT 171
         PRINT 172
         PRINT 82

       ENDIF
C
C
       IF (RP.EQ.2) THEN
       PRINT*
       PRINT*,’Enter File Name   ((Name and Directory’,
     +      ’ must be inside single quotes))’
       PRINT*
         READ*, FNAME
         OPEN (UNIT=2,FILE=FNAME)
C
C
 171   FORMAT(’    POST  ACCEL  SPEED SP-LIMIT TIME/SECT’,
     +   ’  TIME   ACCEL  ENERGY  NOISE’)
 172   FORMAT(’     km   mode   km/hr   km/hr  Minutes’,
     +  ’    min.   m/sec2   kwh    dB’)
         WRITE(2,171)
         WRITE(2,172)
C
         DO 800 I=0,LS-1
           WRITE (UNIT=2,FMT=520) I*S,STATUS(I),MM(5,I),
     +      MM(4,I),MM(6,I),MM(7,I),MM(8,I),MM(10,I),MM(9,I)
 800     CONTINUE
               CLOSE (2)
          PRINT*
C         PRINT 82
         PRINT*
       ENDIF
C
       PRINT*
       PRINT*,’Do you want to see a Speed Profile (1=Yes,0=No)?’
         READ*,RS
        IF (RS.EQ.0) GOTO 999
       PRINT*
C
C
       PRINT*,’Do you want to save Speed Profile in file’,
     +        ’ (1=Yes,0=No)?’
         READ*,RF
        IF (RF.EQ.1) THEN
          PRINT*
          PRINT*,’Enter File Name   ((Name and Directory’,
     +      ’ must be inside single quotes))’
          READ*, SNAME
          OPEN (UNIT=1,FILE=SNAME)
```

```
C
         WRITE(1,FMT=46)
         WRITE(1,FMT=81)
         WRITE(1,FMT=71) SNAME,L,VM
         WRITE(1,FMT=81)
         WRITE(1,FMT=46)
         WRITE(1,FMT=87)
         WRITE(1,FMT=89)
         WRITE(1,FMT=81)
        ENDIF
C
       PRINT*
       PRINT*
       PRINT*,'  POST TIME  V  Vmax GRADE    ',
     +       '       SPEED PROFILE   (km/hr)      ACCELERATION'
       PRINT*,'   km   min   km/hr    %        100       200  ',
     +        '     300       400      500 m/s2'
         PRINT 81
 87    FORMAT(' POST  TIME  V  Vmax GRADE    ',
     +      '       SPEED PROFILE   (km/hr)      ACCELERATION')
 89    FORMAT('  km    min   km/hr    %        100    ',
     +        '   200       300       400       500 m/s2')
 81       FORMAT(80('-'))
       Z(0)=':STATION :         :         :         :         :'
       Z(1)='*        :         :         :         :         :'
       Z(2)=':*       :         :         :         :         :'
       Z(3)=': *      :         :         :         :         :'
       Z(4)=':  *     :         :         :         :         :'
       Z(5)=':   *    :         :         :         :         :'
       Z(6)=':    *   :         :         :         :         :'
       Z(7)=':     *  :         :         :         :         :'
       Z(8)=':      * :         :         :         :         :'
       Z(9)=':       *:         :         :         :         :'
       Z(10)=':        *         :         :         :         :'
       Z(11)=':        :*        :         :         :         :'
       Z(12)=':        : *       :         :         :         :'
       Z(13)=':        :  *      :         :         :         :'
       Z(14)=':        :   *     :         :         :         :'
       Z(15)=':        :    *    :         :         :         :'
       Z(16)=':        :     *   :         :         :         :'
       Z(17)=':        :      *  :         :         :         :'
       Z(18)=':        :       * :         :         :         :'
       Z(19)=':        :        *:         :         :         :'
       Z(20)=':        :         *         :         :         :'
       Z(21)=':        :         :*        :         :         :'
       Z(22)=':        :         : *       :         :         :'
       Z(23)=':        :         :  *      :         :         :'
       Z(24)=':        :         :   *     :         :         :'
       Z(25)=':        :         :    *    :         :         :'
       Z(26)=':        :         :     *   :         :         :'
       Z(27)=':        :         :      *  :         :         :'
       Z(28)=':        :         :       * :         :         :'
       Z(29)=':        :         :        *:         :         :'
       Z(30)=':        :         :         *         :         :'
       Z(31)=':        :         :         :*        :         :'
       Z(32)=':        :         :         : *       :         :'
       Z(33)=':        :         :         :  *      :         :'
       Z(34)=':        :         :         :   *     :         :'
       Z(35)=':        :         :         :    *    :         :'
       Z(36)=':        :         :         :     *   :         :'
       Z(37)=':        :         :         :      *  :         :'
       Z(38)=':        :         :         :       * :         :'
       Z(39)=':        :         :         :        *:         :'
       Z(40)=':        :         :         :         *         :'
       Z(41)=':        :         :         :         :*        :'
       Z(42)=':        :         :         :         : *       :'
       Z(43)=':        :         :         :         :  *      :'
       Z(44)=':        :         :         :         :   *     :'
       Z(45)=':        :         :         :         :    *    :'
       Z(46)=':        :         :         :         :     *   :'
       Z(47)=':        :         :         :         :      *  :'
       Z(48)=':        :         :         :         :       * :'
       Z(49)=':        :         :         :         :        *:'
       Z(50)=':        :         :         :         :         *'
C
         DO 830 I=0,LS-1
           Y1=INT(MM(5,I)/10)
C
C
         IF (RF.EQ.1) THEN
          WRITE(1,FMT=88) I*S,MM(7,I),INT(MM(5,I)),
     + INT(MM(4,I)),SP(I),NINT(MM(1,I)),Z(Y1),STATUS(I),MM(8,I)
         ENDIF
          PRINT 88,I*S,MM(7,I),INT(MM(5,I)),INT(MM(4,I)),
     +     SP(I),NINT(MM(1,I)),Z(Y1),STATUS(I),MM(8,I)
 830     CONTINUE
C
 88          FORMAT(F6.2,F6.1,I4,I4,A2,I2,A50,A1,F5.2)
 520        FORMAT (F8.2,A6,F8.2,F8.2,F8.3,F9.2,F8.3,F8.2,F6.1)
        VA=L*60/(MM(7,LS-1)-DTT)
        SF=100*S
C
        DO 490 I=1,6
          PT(I)=100*ST(I)/(MM(7,LS-1)-(DTT))
 490    CONTINUE
C
        PRINT*
        PRINT 81
C                 ***  NUMBER OF SECTIONS AND SEATS  ***
        IF (HSGT.EQ.1) THEN
           PRINT 56, SST, SEAT
        ENDIF
        IF (HSGT.EQ.2) THEN
           PRINT 55, SST, SEAT
        ENDIF
        IF (HSGT.EQ.3) THEN
           PRINT 54, SST, SEAT
        ENDIF
        IF (HSGT.EQ.4) THEN
           PRINT 53, SST, SEAT
        ENDIF
C
        PRINT*
        PRINT 718, L, MM(7,LS-1)
        PRINT 712,SN,DT
        PRINT*
        PRINT 714, VA
        PRINT 717, VM,ST(6),SS(6)*S
        PRINT*
        PRINT 99,   ’0’,’100’,SS(1)*S,SS(1)*SF/L,ST(1),PT(1)
        PRINT 99, ’101’,’200’,SS(2)*S,SS(2)*SF/L,ST(2),PT(2)
        PRINT 99, ’201’,’300’,SS(3)*S,SS(3)*SF/L,ST(3),PT(3)
        PRINT 99, ’301’,’400’,SS(4)*S,SS(4)*SF/L,ST(4),PT(4)
        PRINT 99, ’401’,’500’,SS(5)*S,SS(5)*SF/L,ST(5),PT(5)
        PRINT 46
        PRINT 57, ENT, L
        PRINT 58, ENA,ENP*100
        PRINT 46
        PRINT 723
        PRINT 724
        PRINT 81
        PRINT*
C
      IF (RF.EQ.1) THEN
        WRITE(1,FMT=46)
        WRITE(1,FMT=81)
        IF (HSGT.EQ.1) THEN
         WRITE(1,FMT=56) SST, SEAT
        ENDIF
        IF (HSGT.EQ.2) THEN
         WRITE(1,FMT=55) SST, SEAT
        ENDIF
        IF (HSGT.EQ.3) THEN
         WRITE(1,FMT=54) SST, SEAT
        ENDIF
        IF (HSGT.EQ.4) THEN
         WRITE(1,FMT=53) SST, SEAT
        ENDIF
        WRITE(1,FMT=46)
        WRITE(1,FMT=718) L, MM(7,LS-1)
        WRITE(1,FMT=46)
        WRITE(1,FMT=712) SN,DT
        WRITE(1,FMT=46)
        WRITE(1,FMT=714) VA
        WRITE(1,FMT=46)
        WRITE(1,FMT=717) VM,ST(6),SS(6)*S
        WRITE(1,FMT=46)
        WRITE(1,FMT=99)  ’0’,’100’,SS(1)*S,SS(1)*SF/L,ST(1),PT(1)
        WRITE(1,FMT=99)’101’,’200’,SS(2)*S,SS(2)*SF/L,ST(2),PT(2)
        WRITE(1,FMT=99)’201’,’300’,SS(3)*S,SS(3)*SF/L,ST(3),PT(3)
        WRITE(1,FMT=99)’301’,’400’,SS(4)*S,SS(4)*SF/L,ST(4),PT(4)
        WRITE(1,FMT=99)’401’,’500’,SS(5)*S,SS(5)*SF/L,ST(5),PT(5)
        WRITE(1,FMT=46)
        WRITE(1,FMT=57) ENT, L
        WRITE(1,FMT=58) ENA,ENP*100
        WRITE(1,FMT=46)
        WRITE(1,FMT=723)
        WRITE(1,FMT=724)
        WRITE (1,FMT=81)
C
C          CLOSE (1)
      ENDIF
C
 46     FORMAT (’ ’)
 53     FORMAT (’The system selected is: The ABB X-2000 ’,
     +     ’having’,I3,’ sections and’,I4,’ seats’)
 54     FORMAT (’The system selected is: The German ICE ’,
     +     ’having’,I3,’ sections and’,I4,’ seats’)
 55     FORMAT (’The system selected is: The French TGV ’,
     +     ’having’,I3,’ sections and’,I4,’ seats’)
 56     FORMAT (’The system selected is: MAGLEV Transrapid 07 ’,
     +     ’having’,I3,’ sections and’,I4,’ seats’)
 57     FORMAT (’Total Energy Consumption :’,F8.2,’ KWH’,
     +          ’             Route Length:’,F8.2,’ km’)
 58     FORMAT (’Average Energy Consumption :’,F6.2,’ KWH/km’,
     +     ’    or  ’,F7.3,’ KWH/100km/pass-seat’)
 71     FORMAT (’FILE: ’,A12,’  ROUTE LENGTH:’,F8.2,
     +          ’ KM      MAX DESIGN SPEED:’,F8.2, ’KM/HR’)
 714    FORMAT(’Average Speed (excluding dwelling time at ’,
     +          ’stations):’, F8.2,’ km/hr’)
 712    FORMAT(’There are’,I3,’ intermediate stations,’,
     +          ’ Avg dwelling time per station:’,F6.2,’ min’)
 99    FORMAT (’Travel at’,A4,’ to’,A4,’ km/hr for:’,F7.2,
     +    ’ km (’,F4.1,’%)  and ’,F6.2,’ minutes (’,F4.1,’%)’)
 717    FORMAT (’Travel at max speed of’,F6.1,
     +  ’ km/hr   for:’, F7.3,’ minutes,    and:’,F7.3,’ km’)
 718   FORMAT(’Total Distance:’,F9.2,’ km,   Total Travel Time’,
     +        ’:’, F9.2,’ min’)
 723   FORMAT(’Speed limits (Vmax):  C=Curve, N=Noise, B=’,
     +       ’Bridge, S=Station, T=Tunnel D=Dummy’)
 724   FORMAT(’Acceleration (m/s2):  A=Accceleration,  D=Decel’,
     +       ’eration,   C=Constant,  S=Stop’)
C
 999      STOP
        END
```

# APPENDIX B
# LISTING OF THE OPERATION SIMULATION MODEL INPUT MENUS WRITTEN IN BASIC

```
REM           ***********************************
REM               OPERATION SIMULATION MODEL
REM                      INPUT MENUS
REM                    MICROSOFT BASIC
REM     ***********************************************
REM

DECLARE SUB WINDOW1 ()
REM
DIM VMD%(20)
DIM ETD%(20)
DIM ETED%(29)
REM
SCREEN 12
COLOR 7   'color of typed words
CLS
CC = 9   'color code used in box drawing
CC2 = 7
CC3 = 4
' XX5(I)      Margin on comment line in Screen 2
LINE (0, 5)-(635, 445), 4, BF
LINE (10, 15)-(625, 435), 0, BF
LINE (15, 20)-(620, 90), CC, B
LINE (15, 110)-(620, 430), CC, B
LOCATE 3, 25
PRINT "HSGT SIMULATION MODEL               Screen 1 of 2"
LOCATE 4, 25
PRINT " By Fadi Emil Nassar "
LOCATE 5, 25
PRINT "University of Florida"
REM
X0 = 15
Y0 = 9
LOCATE Y0, X0
REM  ***   INPUT MENU 1
PRINT "  1.  User Defined HSR or Maglev System"
LOCATE Y0 + 1, X0: PRINT "  2.  Maglev - Tr 07: 2 Sections"
LOCATE Y0 + 2, X0: PRINT "  3.  Maglev - Tr 07: 3 Sections"
LOCATE Y0 + 3, X0: PRINT "  4.  Maglev - Tr 07: 4 Sections"
LOCATE Y0 + 4, X0: PRINT "  5.  Maglev - Tr 07: 5 Sections"
LOCATE Y0 + 5, X0: PRINT "  6.  Maglev - Tr 07: 6 Sections"
LOCATE Y0 + 6, X0: PRINT "  7.  Maglev - Tr 07: 7 Sections"
LOCATE Y0 + 7, X0: PRINT "  8.  Maglev - Tr 07: 8 Sections"
LOCATE Y0 + 8, X0: PRINT "  9.  Maglev - Tr 07: 9 Sections"
LOCATE Y0 + 9, X0: PRINT " 10.  Maglev - Tr 07:10 Sections"
LOCATE Y0 + 10, X0: PRINT " 11.  HSR    - TGV-Texas: 1+8P+1"
LOCATE Y0 + 11, X0: PRINT " 12.  HSR    - TGV-A:    1+10P+1"
LOCATE Y0 + 12, X0: PRINT " 13.  HSR    - ICE:      1+14P+1"
LOCATE Y0 + 13, X0: PRINT " 14.  HSR    - ABB X-2000:  1+5P"
LOCATE Y0 + 14, X0: PRINT " 15.  HSR    - ABB X-2000:  1+6P"
LOCATE Y0 + 15, X0: PRINT " 16.  EXIT"
5 LOCATE 26, 12
INPUT "Enter selected system?   ", PF%
IF (PF% < 1 OR PF% > 16) GOTO 5
IF PF% = 16 GOTO 99
REM   READ SYSTEMS' TOP SPEED
FOR I = 1 TO 15
   READ VMD%(I)
NEXT I
REM  ****   DEFAULT DATA FOR MAX SPEED
DATA 0,500,500,500,500,500,400
DATA 400,350,350,300,300,250,240,240
REM   READ SYSTEMS' TRACK SUPERELEVATION
FOR I = 1 TO 15
   READ ETED%(I)
NEXT I
REM  ****  DEFAULT DATA FOR TRACK SUPERELEVATION
DATA 0,12,12,12,12,12,12,12,12,12,6,6,6,5,5
FOR I = 1 TO 13
   ETD%(I) = 0
NEXT I
ETD%(14) = 6: ETD%(15) = 6
REM
REM  *****  INPUT SCREEN 2
10 SCREEN 12
CLS
LINE (2, 5)-(635, 40), 3, B
LINE (3, 6)-(634, 39), 4, BF
LINE (7, 10)-(630, 35), 0, BF
LINE (2, 50)-(635, 220), 3, B
LINE (3, 51)-(634, 219), 4, BF
LINE (7, 55)-(630, 215), 0, BF
LINE (2, 230)-(635, 330), 3, B
LINE (3, 231)-(634, 329), 4, BF
LINE (7, 235)-(630, 325), 0, BF
LINE (2, 340)-(635, 415), 3, B
LINE (3, 341)-(634, 414), 4, BF
LINE (7, 345)-(630, 410), 0, BF
X1 = 3: X2 = 40: Y1 = 5
LOCATE 2, 27
PRINT " HSGT SIMULATION MODEL              Screen 2 of 2"
LOCATE Y1, X1: PRINT "Route Length (km):"
LOCATE Y1 + 2, X1: PRINT "Section Length (km):"
PRINT ""
LOCATE Y1 + 4, X1: PRINT "Design Speed (km/hr):"
PRINT ""
LOCATE Y1 + 6, X1: PRINT "Initial Speed (km/hr):"
PRINT ""
LOCATE Y1 + 8, X1: PRINT "Final Speed (km/hr):"
PRINT ""
REM
LOCATE Y1, X2: PRINT "Route Filename:"
```

```
PRINT ""
LOCATE Y1 + 2, X2: PRINT "No of Intermediate Stations:"
PRINT ""
LOCATE Y1 + 4, X2: PRINT "No of Grade Segments:"
PRINT ""
LOCATE Y1 + 6, X2: PRINT "No of Horizontal Curves:"
PRINT ""
LOCATE Y1 + 8, X2: PRINT "No of Speed Restrictions:"
REM
PRINT ""
LOCATE Y1 + 11, 3: PRINT "Typ. Track Superelevation (deg):"
LOCATE Y1 + 11, X2 + 10: PRINT "Exceptional (degree):"
LOCATE Y1 + 13, X1: PRINT "Typ Lateral Acceleration (m/s2):"
LOCATE Y1 + 13, X2 + 10: PRINT "  Exceptional (m/s2):"
LOCATE Y1 + 15, X1: PRINT "Effective Train Tilt (degree):"
LOCATE Y1 + 15, X2 + 6: PRINT "Deceleration Rate (m/s2):"
LOCATE Y1 + 18, X1: PRINT "Save Simulation Data (Y/N)?"
LOCATE Y1 + 18, X2: PRINT "Enter Filename:"
LOCATE Y1 + 20, X1: PRINT "Save Speed Profile (Y/N)?"
LOCATE Y1 + 20, X2: PRINT "Enter Filename:"
REM
REM
CALL WINDOW1: LOCATE 28, 5
PRINT " 0 ==> Exit,   1 ==>  SPEED PROFILE  "
LOCATE Y1, X1 + 25: INPUT "", L!
IF CINT(L!) = 1 THEN
        L! = 50
        S! = .5
        GOTO 15
END IF
IF CINT(L!) = 0 GOTO 99
CALL WINDOW1: LOCATE 28, 5
PRINT "        RECOMMENDED VALUE BETWEEN 0.1 AND 0.5 KM  "
LOCATE Y1 + 2, X1 + 25: INPUT "", S!
ALL WINDOW1: LOCATE 28, 5
PRINT "TOP SPEED OF SELECTED SYSTEM"; VMD%(PF%); " KM/HR "
LOCATE Y1 + 4, X1 + 25: INPUT "", VM!
CALL WINDOW1: LOCATE 28, 5
PRINT " INITIAL LOCATION IS A STATION ==> INITIAL SPEED=0"
LOCATE Y1 + 6, X1 + 25: INPUT "", VI!
CALL WINDOW1: LOCATE 28, 5
PRINT "IF FINAL LOCATION IS A STATION ==> FINAL SPEED = 0"
LOCATE Y1 + 8, X1 + 25: INPUT "", VF!
REM
CALL WINDOW1: LOCATE 28, 5
PRINT "  INCLUDE DRIVE AND DIRECTORY    "
LOCATE Y1, X2 + 16: INPUT "", DNAME$
CALL WINDOW1: LOCATE 28, 5
PRINT "     ENTER NUMBER OF ALL INTERMEDIATE STATIONS  "
LOCATE Y1 + 2, X2 + 30: INPUT "", SN%
CALL WINDOW1: LOCATE 28, 5
PRINT "         ENTER NUMBER OF ALL GRADE SEGMENTS     "
```

```
LOCATE Y1 + 4, X2 + 30: INPUT "", GN%
CALL WINDOW1: LOCATE 28, 5
PRINT "       ENTER NUMBER OF ALL HORIZONTAL CURVES    "
LOCATE Y1 + 6, X2 + 30: INPUT "", CN%
CALL WINDOW1: LOCATE 28, 5
PRINT "     ENTER NUMBER OF ALL SPEED RESTRICTION ZONES"
LOCATE Y1 + 8, X2 + 30: INPUT "", ZN%
REM
IF CN% = 0 GOTO 15
CALL WINDOW1: LOCATE 28, 5
PRINT "TYP TRACK SUPERELEVATION "; ETED%(PF%) - 2; "DEG"
LOCATE Y1 + 11, X1 + 39: INPUT "", ETT!
CALL WINDOW1: LOCATE 28, 5
PRINT " EX TRACK SUPERELEVATION "; ETED%(PF%); "DEGREES"
LOCATE Y1 + 11, X2 + 32: INPUT "", ETE!
CALL WINDOW1: LOCATE 28, 5
PRINT "TYPICAL ALLOWABLE LATERAL ACCELERATION / 0.8 M/S2"
LOCATE Y1 + 13, X1 + 37: INPUT "", ELT!
CALL WINDOW1: LOCATE 28, 5
PRINT "EXCEPT. ALLOWABLE LATERAL ACCELERATION / 1 M/S2"
LOCATE Y1 + 13, X2 + 32: INPUT "", ELE!
CALL WINDOW1: LOCATE 28, 5
PRINT "EFFECTIVE TILT OF SYSTEM "; ETD%(PF%); "DEGREES"
LOCATE Y1 + 15, X1 + 31: INPUT "", ET!
15 CALL WINDOW1: LOCATE 28, 5
PRINT "COMFORT. DECEL. RATE / BETWEEN 0.4 AND 1.0 M/SEC2"
LOCATE Y1 + 15, X2 + 32: INPUT "", DDI!
CALL WINDOW1: LOCATE 28, 5
PRINT "OUTPUT CONSISTS OF ASCII FILE OF MAIN PARAMETERS"
LOCATE Y1 + 18, X1 + 29: INPUT "", ANSWER1$
IF ANSWER1$ = "Y" OR ANSWER1$ = "y" THEN
        RP% = 2
        LOCATE Y1 + 18, X2 + 16: INPUT "", TNAME$
        GOTO 20
ELSE
        RP% = 1
END IF
20 CALL WINDOW1: LOCATE 28, 5
PRINT " OUTPUT CONSISTS OF A SPEED PROFILE AND PARAMETERS"
LOCATE Y1 + 20, X1 + 29: INPUT "", ANSWER2$
IF ANSWER2$ = "y" OR ANSWER2$ = "Y" THEN
        RF% = 1
        LOCATE Y1 + 20, X2 + 16: INPUT "", SNAME$
        GOTO 30
ELSE
        RF% = 2
END IF
REM
30 LINE (149, 179)-(471, 251), 3, BF
LINE (152, 182)-(468, 248), 4, BF
LINE (172, 202)-(448, 228), 3, BF
LINE (175, 205)-(445, 225), 0, BF
```

```
LOCATE 14, 23
REM COLOR CC3
INPUT "Are Input Values Correct (Y/N)? ", ANSWER3$
IF ANSWER3$ = "N" OR ANSWER3$ = "n" GOTO 10
REM
LINE (49, 179)-(571, 251), 3, BF
LINE (52, 182)-(568, 248), 4, BF
LINE (70, 200)-(550, 230), 3, BF
LINE (75, 205)-(545, 225), 0, BF
LOCATE 14, 13
REM COLOR CC3
INPUT "Want to Edit Route Data File (Y/N)? ", ANSWER5$
IF ANSWER5$ = "Y" OR ANSWER5$ = "y" THEN
        DOSEDIT$ = "C:\DOS\EDIT "
        SHELL DOSEDIT$ + DNAME$
END IF
REM  DEVELOP INPUT FILE FOR FORTRAN PROGRAM
REM
FS$ = "#######.###"
OPEN "FILE1.DAT" FOR OUTPUT AS #1
REM OPEN "FILE1.DAT" FOR OUTPUT AS #1
PRINT #1, USING FS$; PF%   'BASIC(1)
PRINT #1, USING FS$; L!    'BASIC(2)
PRINT #1, USING FS$; S!    'BASIC(3)
PRINT #1, USING FS$; VM!   'BASIC(4)
PRINT #1, USING FS$; VI!   'BASIC(5)
PRINT #1, USING FS$; VF!   'BASIC(6)
PRINT #1, USING FS$; SN%   'BASIC(7)
PRINT #1, USING FS$; CN%   'BASIC(8)
PRINT #1, USING FS$; GN%    'BASIC(9)
PRINT #1, USING FS$; ZN%    'BASIC(10)
PRINT #1, USING FS$; ETT!    'BASIC(11)
PRINT #1, USING FS$; ETE!   'BASIC(12)
PRINT #1, USING FS$; ELT!   'BASIC(13)
PRINT #1, USING FS$; ELE!   'BASIC(14)
PRINT #1, USING FS$; ET!    'BASIC(15)
PRINT #1, USING FS$; DDI!   'BASIC(16)
PRINT #1, USING FS$; RP%    'BASIC(17)
PRINT #1, USING FS$; RF%    'BASIC(18)
CLOSE #1
OPEN "FILE2.DAT" FOR OUTPUT AS #2
REM OPEN "FILE2.DAT" FOR OUTPUT AS #2
PRINT #2, UCASE$(DNAME$)
PRINT #2, UCASE$(TNAME$)
PRINT #2, UCASE$(SNAME$)
CLOSE #2
XX%(1) = 3:  XXX$(1) = ""
XX%(2) = 3:  XXX$(2) = ""
XX%(3) = 3:  XXX$(3) = ""
XX%(4) = 3:  XXX$(4) = ""
XX%(5) = 3:  XXX$(5) = ""
XX%(6) = 3:  XXX$(6) = ""
```

```
XX%(7) = 3:  XXX$(7) = ""
XX%(8) = 3:  XXX$(8) = ""
XX%(9) = 3:  XXX$(9) = ""
XX%(10) = 3:  XXX$(10) = ""
XX%(11) = 3:  XXX$(11) = ""
XX%(12) = 3:  XXX$(12) = ""
99 END
-------------------------------------------------------
SUB WINDOW1
        LINE (2, 422)-(635, 457), 3, BF
        LINE (4, 424)-(633, 455), 4, BF
        LINE (9, 429)-(628, 450), 3, BF
        LINE (11, 431)-(626, 448), 0, BF
REM        LINE (7, 430)-(630, 450), 3, B
REM        LINE (7, 430)-(630, 450), 0, BF
REM        LOCATE 28, 5 + XX%(I): PRINT XXX$(I)
END SUB
--------------------------------------------------------
```

# APPENDIX C

# ROUTE ALIGNMENT DATA OF THE TAMPA-ORLANDO CORRIDOR OBTAINED FROM FDOT AND ROUTE INPUT FILES FOR THE SIMULATION MODEL

## SECTION I: I-275 FROM TAMPA BAY TO I-4 (6.8 MILES)

| STATION | R (FEET) | REDUCED SPEED (mph) | CURVE LENGTH (FEET) | NOTES |
|---|---|---|---|---|
| 90 | Tan | | | Tampa Bay |
| 145 | >13,000’ | No reduction | 1000’ | |
| 155 | Tan | | | |
| 170 | 5000’ | 100 | 2500’ | Westshore Blvd |
| 195 | Tan | | | |
| 205 | 2500’ | 70 | 2000’ | Lois Ave |
| 225 | Tan | | | |
| 240 | 2500’ | 70 | 2000 | Dale Mabry |
| 260 | Tan | | | |
| 352=390 | 7000’ | 125 | 800’ | Station equality |
| 398 | Tan | | | |
| 403 | >13,000’ | No reduction | 2200 | |
| 425 | Tan | | | |
| 435 | 1500’ | 55 | 1700’ | Orange St |
| 452 | Tan | | | |
| 465 | 2000’ | 65 | 2000’ | I-275/I-4 Interchange |
| 485 | Tan | | | I-4 |

## SECTION II:
## I-4 FROM I-275 TO HILLSBOROUGH/POLK COUNTY LINE (25 MILES)

| STATION | R (FEET) | REDUCED SPEED (mph) | CURVE LENGTH (FEET) | NOTES |
|---|---|---|---|---|
| 455 | Tan | | | |
| 575 | 7000’ | 125 | 4000’ | 50th St. (US 41) |
| 615 | Tan | | | |
| 652=1085 | Tan | | | Station equality |
| 1190 | 3000’ | 80 | 2700’ | West of US 301 |
| 1217 | Tan | | | |
| 1225 | 10,000’ | 160 | 4000’ | Six Mile Creek |
| 1265 | Tan | | | |
| 1305 | 7,000’ | 125 | 2000’ | West of I-75 |
| 1325 | Tan | | | |
| 1365 | 13,000’ | 180 | 800’ | Williams Rd. |
| 1373 | Tan | | | |
| 1460 | 7,000’ | 125 | 2000’ | W. of Kingsway Rd. |
| 1480 | Tan | | | |
| 1560 | 7,000’ | 125 | 1000’ | W. of Antioch-McIntosh |
| 1570 | Tan | | | |
| 1680 | 7,000’ | 125 | 1000’ | W. of Fritzke Rd. |
| 1690 | Tan | | | |
| 1905 | 7,000’ | 125 | 2500’ | SR 566 |
| 1930=177 | Tan | | | Station equality |
| 250 | 4,500 | 95 | 1,500’ | Wheeler St. (SR 39) |
| 265 | Tan | | | |
| 470 | Tan | | | |

## SECTION III: I-4 THROUGH POLK COUNTY (DISTRICT 1) (32 MILES)

| STATION | R (FEET) | REDUCED SPEED (MPH) | CURVE LENTH (FEET) | NOTES |
|---|---|---|---|---|
| 470 | Tan | | | Hillsborough/ Polk County Line |
| 520 | 3000' | 80 | 2500' | Polk County Parkway |
| 545 | Tan | | | |
| 840 | 7000' | 125 | 1200' | Carpenters Way Road |
| 852 | Tan | | | |
| 865 | 7000' | 125 | 3000' | SR 582 |
| 895 | Tan | | | |
| 940 | 13000' | 180 | 2500' | Old Cambee Rd |
| 965 | Tan | | | |
| 1315 | 13000' | 180 | 4000' | Mt. Olive Church Road |
| 1355 | Tan | | | |
| 1460 | 10000' | 160 | 7000' | SR 559 to SR 557A |
| 1530 | Tan | | | |
| 1540 | >13000' | No Reduction | 7000' | |
| 1610 | Tan | | | |
| 1755 | >20000' | No Reduction | 1500' | |
| 1770 | Tan | | | |
| 1875 | >13000' | No Reduction | 1800' | |
| 1893 | Tan | | | |
| 1935 | >13000' | No Reduction | 3500' | |
| 1970 | Tan | | | |
| 2140 | 13000' | 180 | 2000' | |
| 2160 | Tan | | | Polk/Osceola County Line |

## SECTION IV: I-4 FROM POLK/OSCEOLA COUNTY LINE TO BEELINE EXPRESSWAY (13.4 MILES)

| STATION | R (FEET) | REDUCED SPEED (MPH) | CURVE LENGTH (FEET) | NOTES |
|---|---|---|---|---|
| 2160 | Tan | | | Polk/Osceola County Line |
| 2487 | Tan | | | US 192 |
| 2552 | Tan | | | Osceola/Orange County Line |
| 2820 | 2800' | 75 | 2200' | Central Florida Parkway (Big Sand Lake) |
| 2842 | Tan | | | |
| 2865 | Tan | | | BeeLine Exp'wy (SR 528) |

## SECTION V: I-4 FROM BEE LINE EXPRESSWAY TO ORANGE/SEMINOLE COUNTY LINE (17.2 MILES)

| STATION | R (FEET) | REDUCED SPEED (MPH) | CURVE LENTH (FEET) | NOTES |
|---|---|---|---|---|
| 2865 | Tan | | | BeeLine Exp'wy (SR 528) |
| 2980 | 2800' | 75 | 2500' | N. of Sand Lake Rd (SR 482) |
| 3005 | Tan | | | |
| 3094 | Tan | | | Florida's Turnpike |
| 3132 | 7000' | 125 | 1800' | Shingle Creek |
| 3150 | Tan | | | |
| 3215 | 2600' | 70 | 2500' | John Young Parkway |
| 3240 | Tan | | | |
| 3275 | 5000' | 100 | 3500' | Orange Blossom Tr (SR 500) |
| 3310 | Tan | | | |
| 3325 | 2000' | 65 | 2000' | Kaley Ave |
| 3345 | Tan | | | |
| 3375 | 1800 | 60 | 1200' | Gore Ave |
| 3387 | Tan | | | |
| 3392 | 4000' | 90 | 2000' | East West Exp'wy |
| 3412 | Tan | | | |
| 3455 | 5000' | 100 | 3000' | Colonial Drive |
| 3485 | Tan | | | |
| 3505 | 4000' | 90 | 1500' | New Hampshire St |
| 3520 | Tan | | | |
| 3535 | 4000' | 80 | 2000' | Winter Park & Hazel St (Bank to back curve) |
| 3555 | Tan | | | |
| 3570 | 2000' | 65 | 2000' | Par Ave to Minnesota Ave |

| STATION | R (FEET) | REDUCED SPEED (MPH) | CURVE LENTH (FEET) | NOTES |
|---|---|---|---|---|
| 3590 | Tan | | | |
| 3620 | 1800' | 60 | 1200' | Fairbanks Ave |
| 3632 | Tan | | | |
| 3725 | 4000' | 80 | 4000' | Maitland Blvd (back to back curves) |
| 3765 | Tan | | | |
| 3775 | Tan | | | Orange/Seminole County Line |

# ORLANDO-TAMPA ROUTE
# ROUTE INPUT FILE BASED ON SPEED LIMITS
# CASE A

| | | | |
|---|---|---|---|
| 1.676 | 0.305 | 300. | |
| 2.438 | 0.762 | 160. | Westshore Blvd |
| 3.505 | 0.610 | 112. | Lois Avenue |
| 4.572 | 0.610 | 112. | Dale Mabry |
| 7.986 | 0.244 | 200. | Station Equality |
| 8.382 | 0.671 | 300. | |
| 9.357 | 0.518 | 88. | Orange Street |
| 10.272 | 0.610 | 104. | I-275/I-4 Interchange |
| 14.539 | 1.219 | 200. | 50th Street (US 41) |
| 20.086 | 0.363 | 128. | West of US 301 |
| 21.153 | 1.219 | 256. | Six Mile Creek |
| 23.592 | 0.610 | 200. | West of I-75 |
| 25.420 | 0.244 | 289. | Williams Road |
| 28.316 | 0.610 | 200. | West of Kingsway Road |
| 31.364 | 0.305 | 200. | West of Antioch-McIntosh |
| 35.022 | 0.305 | 200. | West of Fritzke Road |
| 41.880 | 0.762 | 200. | SR 566 |
| 44.867 | 0.457 | 152. | Wheeler Street (SR 39) |
| 53.096 | 0.762 | 128. | Polk County Parkway |
| 62.850 | 0.366 | 200. | Carpenters Way Road |
| 63.612 | 0.914 | 200. | SR 582 |
| 65.898 | 0.762 | 289. | Old Cambee Road |
| 77.328 | 1.219 | 289. | Mount Olive Church Road |
| 81.747 | 2.134 | 257. | SR 559 to SR 557A |
| 84.186 | 2.134 | 300. | |
| 90.739 | 0.457 | 350. | |
| 94.397 | 0.549 | 300. | |
| 96.225 | 1.067 | 300. | |
| 102.474 | 0.610 | 289. | |
| 123.200 | 0.671 | 120. | Central Florida Parkway |
| 128.077 | 0.762 | 120. | N. Sand Lake Rd. (SR482) |
| 132.710 | 0.549 | 200. | Shingle Creek |
| 135.240 | 0.762 | 112. | John Young Parkway |
| 137.069 | 1.067 | 161. | Orange Blossom T.-SR500 |
| 138.593 | 0.610 | 104. | Kaley Avenue |
| 140.117 | 0.366 | 96. | Gore Avenue |
| 140.635 | 0.610 | 145. | East West Expressway |
| 142.555 | 0.914 | 161. | Colonial Drive |
| 144.079 | 0.457 | 145. | New Hampshire Street |
| 144.993 | 0.610 | 128. | Winter Park & Hazel St. |
| 146.060 | 0.610 | 104. | Par Ave to Minnesota Ave |
| 147.584 | 0.366 | 96. | Fairbanks Avenue |
| 150.785 | 1.215 | 129. | Maitland Blvd (curve) |

# ORLANDO-TAMPA ROUTE
# ROUTE INPUT FILE BASED ON CURVE RADIUS
## CASE B

| | | | |
|---|---|---|---|
| 1.676 | 0.305 | 3962. | |
| 2.438 | 0.762 | 1524. | Westshore Blvd |
| 3.505 | 0.610 | 762. | Lois Avenue |
| 4.572 | 0.610 | 762. | Dale Mabry |
| 7.986 | 0.244 | 2134. | Station Equality |
| 8.382 | 0.671 | 3962. | |
| 9.357 | 0.518 | 457. | Orange Street |
| 10.272 | 0.610 | 610. | I-275/I-4 Interchange |
| 14.539 | 1.219 | 2134. | 50th Street (US 41) |
| 20.086 | 0.363 | 914. | West of US 301 |
| 21.153 | 1.219 | 3048. | Six Mile Creek |
| 23.592 | 0.610 | 2134. | West of I-75 |
| 25.420 | 0.244 | 3962. | Williams Road |
| 28.316 | 0.610 | 2134. | West of Kingsway Road |
| 31.364 | 0.305 | 2134. | West of Antioch-McIntosh |
| 35.022 | 0.305 | 2134. | West of Fritzke Road |
| 41.880 | 0.762 | 2134. | SR 566 |
| 44.867 | 0.457 | 1372. | Wheeler Street (SR 39) |
| 53.096 | 0.762 | 914. | Polk County Parkway |
| 62.850 | 0.366 | 2134. | Carpenters Way Road |
| 63.612 | 0.914 | 2134. | SR 582 |
| 65.898 | 0.762 | 3962. | Old Cambee Road |
| 77.328 | 1.219 | 3962. | Mount Olive Church Road |
| 81.747 | 2.134 | 3048. | SR 559 to SR 557A |
| 84.186 | 2.134 | 3962. | |
| 90.739 | 0.457 | 6096. | |
| 94.397 | 0.549 | 3962. | |
| 96.225 | 1.067 | 3962. | |
| 102.474 | 0.610 | 3962. | |
| 123.200 | 0.671 | 853. | Central Florida Parkway |
| 128.077 | 0.762 | 853. | N. Sand Lake Rd. (SR482) |
| 132.710 | 0.549 | 2134. | Shingle Creek |
| 135.240 | 0.762 | 792. | John Young Parkway |
| 137.069 | 1.067 | 1524. | Orange Blossom T.-SR500 |
| 138.593 | 0.610 | 610. | Kaley Avenue |
| 140.117 | 0.366 | 549. | Gore Avenue |
| 140.635 | 0.610 | 1219. | East West Expressway |
| 142.555 | 0.914 | 1524. | Colonial Drive |
| 144.079 | 0.457 | 1219. | New Hampshire Street |
| 144.993 | 0.610 | 1219. | Winter Park & Hazel St. |
| 146.060 | 0.610 | 610. | Par Ave to Minnesota Ave |
| 147.584 | 0.366 | 549. | Fairbanks Avenue |
| 150.785 | 1.215 | 1219. | Maitland Blvd (curve) |

# ORLANDO-TAMPA ROUTE
# ROUTE INPUT FILE BASED ON CURVE RADIUS
# PLUS A STATION AT LAKELAND
# CASE C

```
 60.0        2.0             Lakeland Station
  1.676      0.305  3962.
  2.438      0.762  1524.    Westshore Blvd
  3.505      0.610   762.    Lois Avenue
  4.572      0.610   762.    Dale Mabry
  7.986      0.244  2134.    Station Equality
  8.382      0.671  3962.
  9.357      0.518   457.    Orange Street
 10.272      0.610   610.    I-275/I-4 Interchange
 14.539      1.219  2134.    50th Street (US 41)
 20.086      0.363   914.    West of US 301
 21.153      1.219  3048.    Six Mile Creek
 23.592      0.610  2134.    West of I-75
 25.420      0.244  3962.    Williams Road
 28.316      0.610  2134.    West of Kingsway Road
 31.364      0.305  2134.    West of Antioch-McIntosh
 35.022      0.305  2134.    West of Fritzke Road
 41.880      0.762  2134.    SR 566
 44.867      0.457  1372.    Wheeler Street (SR 39)
 53.096      0.762   914.    Polk County Parkway
 62.850      0.366  2134.    Carpenters Way Road
 63.612      0.914  2134.    SR 582
 65.898      0.762  3962.    Old Cambee Road
 77.328      1.219  3962.    Mount Olive Church Road
 81.747      2.134  3048.    SR 559 to SR 557A
 84.186      2.134  3962.
 90.739      0.457  6096.
 94.397      0.549  3962.
 96.225      1.067  3962.
102.474      0.610  3962.
123.200      0.671   853.    Central Florida Parkway
128.077      0.762   853.    N. Sand Lake Rd. (SR482)
132.710      0.549  2134.    Shingle Creek
135.240      0.762   792.    John Young Parkway
137.069      1.067  1524.    Orange Blossom T.-SR500
138.593      0.610   610.    Kaley Avenue
140.117      0.366   549.    Gore Avenue
140.635      0.610  1219.    East West Expressway
142.555      0.914  1524.    Colonial Drive
144.079      0.457  1219.    New Hampshire Street
144.993      0.610  1219.    Winter Park & Hazel St.
146.060      0.610   610.    Par Ave to Minnesota Ave
147.584      0.366   549.    Fairbanks Avenue
150.785      1.215  1219.    Maitland Blvd (curve)
```

# ORLANDO-TAMPA ROUTE
# ROUTE INPUT FILE BASED ON CURVE RADIUS
# PLUS A STATION AT LAKELAND
# PLUS ELIMINATION OF SIX CURVES
# CASE D

| | | | |
|---|---|---|---|
| 60.0 | 2.0 | | Lakeland Station |
| 1.676 | 0.305 | 3962. | |
| 2.438 | 0.762 | 1524. | Westshore Blvd |
| 3.505 | 0.610 | 762. | Lois Avenue |
| 4.572 | 0.610 | 762. | Dale Mabry |
| 7.986 | 0.244 | 2134. | Station Equality |
| 8.382 | 0.671 | 3962. | |
| 9.357 | 0.518 | 457. | Orange Street |
| 10.272 | 0.610 | 610. | I-275/I-4 Interchange |
| 14.539 | 1.219 | 2134. | 50th Street (US 41) |
| 21.153 | 1.219 | 3048. | Six Mile Creek |
| 23.592 | 0.610 | 2134. | West of I-75 |
| 25.420 | 0.244 | 3962. | Williams Road |
| 28.316 | 0.610 | 2134. | West of Kingsway Road |
| 31.364 | 0.305 | 2134. | West of Antioch-McIntosh |
| 35.022 | 0.305 | 2134. | West of Fritzke Road |
| 41.880 | 0.762 | 2134. | SR 566 |
| 62.850 | 0.366 | 2134. | Carpenters Way Road |
| 63.612 | 0.914 | 2134. | SR 582 |
| 65.898 | 0.762 | 3962. | Old Cambee Road |
| 77.328 | 1.219 | 3962. | Mount Olive Church Road |
| 81.747 | 2.134 | 3048. | SR 559 to SR 557A |
| 84.186 | 2.134 | 3962. | |
| 90.739 | 0.457 | 6096. | |
| 94.397 | 0.549 | 3962. | |
| 96.225 | 1.067 | 3962. | |
| 102.474 | 0.610 | 3962. | |
| 132.710 | 0.549 | 2134. | Shingle Creek |
| 137.069 | 1.067 | 1524. | Orange Blossom T.-SR500 |
| 138.593 | 0.610 | 610. | Kaley Avenue |
| 140.117 | 0.366 | 549. | Gore Avenue |
| 140.635 | 0.610 | 1219. | East West Expressway |
| 142.555 | 0.914 | 1524. | Colonial Drive |
| 144.079 | 0.457 | 1219. | New Hampshire Street |
| 144.993 | 0.610 | 1219. | Winter Park & Hazel St. |
| 146.060 | 0.610 | 610. | Par Ave to Minnesota Ave |
| 147.584 | 0.366 | 549. | Fairbanks Avenue |
| 150.785 | 1.215 | 1219. | Maitland Blvd (curve) |

## APPENDIX D
## SAMPLE SPEED PROFILE OUTPUT OF THE OPERATION SIMULATION MODEL

```
--------------------------------------------------------------------------------
FILE: OUTPUT.DOC    ROUTE LENGTH:  150.00 KM      MAX DESIGN SPEED:  450.00KM/HR
--------------------------------------------------------------------------------

 POST  TIME  V  Vmax GRADE            SPEED PROFILE   (km/hr)       ACCELERATION
  km    min   km/hr    %        100       200       300       400       500 m/s2
--------------------------------------------------------------------------------
  0.00   0.0   0   0 S 0:STATION :         :         :         :         :A 0.78
  0.50   0.6 100 450   0:        *         :         :         :         :A 0.78
  1.00   0.8 138 450   0:        :  *      :         :         :         :A 0.70
  1.50   1.0 167 399 C 0:        :     *   :         :         :         :A 0.68
  2.00   1.2 190 247 C 0:        :        *:         :         :         :A 0.65
  2.50   1.4 211 247 C 0:        :         :*        :         :         :A 0.65
  3.00   1.5 199 247 C 0:        :        *:         :         :         :D-0.39
  3.50   1.7 175 175 C 0:        :      *  :         :         :         :D-0.70
  4.00   1.8 175 175 C 0:        :      *  :         :         :         :C 0.00
  4.50   2.0 175 175 C 0:        :      *  :         :         :         :C 0.00
  5.00   2.2 175 175 C 0:        :      *  :         :         :         :C 0.00
  5.50   2.3 197 450   0:        :        *:         :         :         :A 0.65
  6.00   2.5 218 450   0:        :         :*        :         :         :A 0.65
  6.50   2.6 235 450   0:        :         :  *      :         :         :A 0.60
  7.00   2.7 233 450   0:        :         :  *      :         :         :D-0.05
  7.50   2.9 213 293 C 0:        :         :*        :         :         :D-0.70
  8.00   3.0 191 399 C 0:        :        *:         :         :         :D-0.70
  8.50   3.2 165 399 C 0:        :     *   :         :         :         :D-0.70
  9.00   3.4 135 135 C 0:        :  *      :         :         :         :D-0.70
  9.50   3.6 135 135 C 0:        :  *      :         :         :         :C 0.00
 10.00   3.8 156 156 C 0:        :    *    :         :         :         :A 0.48
 10.50   4.0 156 156 C 0:        :    *    :         :         :         :C 0.00
 11.00   4.2 181 450   0:        :       * :         :         :         :A 0.65
 11.50   4.3 203 450   0:        :         *         :         :         :A 0.65
 12.00   4.5 221 450   0:        :         : *       :         :         :A 0.60
 12.50   4.6 238 450   0:        :         :  *      :         :         :A 0.60
 13.00   4.7 254 450   0:        :         :    *    :         :         :A 0.60
 13.50   4.9 268 450   0:        :         :     *   :         :         :A 0.55
 14.00   5.0 281 450   0:        :         :       * :         :         :A 0.55
 14.50   5.1 293 293 C 0:        :         :        *:         :         :A 0.54
 15.00   5.2 293 293 C 0:        :         :        *:         :         :C 0.00
 15.50   5.3 293 293 C 0:        :         :        *:         :         :C 0.00
 16.00   5.4 305 450   0:        :         :         *         :         :A 0.55
 16.50   5.5 315 450   0:        :         :         :*        :         :A 0.50
 17.00   5.6 302 450   0:        :         :         *         :         :D-0.64
 17.50   5.7 286 450   0:        :         :       * :         :         :D-0.70
 18.00   5.8 270 450   0:        :         :      *  :         :         :D-0.70
 18.50   5.9 253 450   0:        :         :    *    :         :         :D-0.70
 19.00   6.0 234 450   0:        :         :  *      :         :         :D-0.70
 19.50   6.1 214 450   0:        :         :*        :         :         :D-0.70
 20.00   6.3 191 191 C 0:        :        *:         :         :         :D-0.70
 20.50   6.4 212 450   0:        :         :*        :         :         :A 0.65
 21.00   6.6 230 350 C 0:        :         :  *      :         :         :A 0.60
 21.50   6.7 246 350 C 0:        :         :   *     :         :         :A 0.60
 22.00   6.8 261 350 C 0:        :         :     *   :         :         :A 0.60
 22.50   6.9 275 450   0:        :         :      *  :         :         :A 0.55
 23.00   7.0 287 450   0:        :         :       * :         :         :A 0.55
 23.50   7.1 293 293 C 0:        :         :        *:         :         :A 0.24
 24.00   7.2 293 293 C 0:        :         :        *:         :         :C 0.00
 24.50   7.3 305 450   0:        :         :         *         :         :A 0.55
 25.00   7.4 315 399 C 0:        :         :         :*        :         :A 0.50
 25.50   7.5 325 399 C 0:        :         :         : *       :         :A 0.50
```

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26.00   7.6 335 450   0:        :         :         :  *      :         :A 0.50
26.50   7.7 336 450   0:        :         :         :  *      :         :A 0.05
27.00   7.8 322 450   0:        :         :         : *       :         :D-0.70
27.50   7.9 308 450   0:        :         :         *         :         :D-0.70
28.00   8.0 293 293 C 0:        :         :        *:         :         :D-0.70
28.50   8.1 293 293 C 0:        :         :        *:         :         :C 0.00
29.00   8.2 305 450   0:        :         :         *         :         :A 0.55
29.50   8.3 315 450   0:        :         :         :*        :         :A 0.50
30.00   8.4 322 450   0:        :         :         : *       :         :A 0.35
30.50   8.5 308 450   0:        :         :         *         :         :D-0.70
31.00   8.6 293 293 C 0:        :         :        *:         :         :D-0.70
31.50   8.7 293 293 C 0:        :         :        *:         :         :C 0.00
32.00   8.8 305 450   0:        :         :         *         :         :A 0.55
32.50   8.9 315 450   0:        :         :         :*        :         :A 0.50
33.00   9.0 325 450   0:        :         :         : *       :         :A 0.50
33.50   9.1 335 450   0:        :         :         :  *      :         :A 0.50
34.00   9.2 322 450   0:        :         :         : *       :         :D-0.65
34.50   9.3 308 450   0:        :         :         *         :         :D-0.70
35.00   9.4 293 293 C 0:        :         :        *:         :         :D-0.70
35.50   9.5 305 450   0:        :         :         *         :         :A 0.55
36.00   9.6 315 450   0:        :         :         :*        :         :A 0.50
36.50   9.7 325 450   0:        :         :         : *       :         :A 0.50
37.00   9.7 335 450   0:        :         :         :  *      :         :A 0.50
37.50   9.8 344 450   0:        :         :         :   *     :         :A 0.50
38.00   9.9 354 450   0:        :         :         :    *    :         :A 0.50
38.50  10.0 362 450   0:        :         :         :     *   :         :A 0.45
39.00  10.1 362 450   0:        :         :         :     *   :         :C 0.00
39.50  10.2 349 450   0:        :         :         :   *     :         :D-0.70
40.00  10.3 336 450   0:        :         :         :  *      :         :D-0.70
40.50  10.3 322 450   0:        :         :         : *       :         :D-0.70
41.00  10.4 308 450   0:        :         :         *         :         :D-0.70
41.50  10.5 293 293 C 0:        :         :        *:         :         :D-0.70
42.00  10.6 293 293 C 0:        :         :        *:         :         :C 0.00
42.50  10.7 293 293 C 0:        :         :        *:         :         :C 0.00
43.00  10.8 287 450   0:        :         :       * :         :         :D-0.27
43.50  11.0 270 450   0:        :         :      *  :         :         :D-0.70
44.00  11.1 253 450   0:        :         :    *    :         :         :D-0.70
44.50  11.2 235 235 C 0:        :         :  *      :         :         :D-0.70
45.00  11.3 235 235 C 0:        :         :  *      :         :         :C 0.00
45.50  11.4 251 450   0:        :         :    *    :         :         :A 0.60
46.00  11.6 264 450   0:        :         :     *   :         :         :A 0.55
46.50  11.7 278 450   0:        :         :      *  :         :         :A 0.55
47.00  11.8 290 450   0:        :         :        *:         :         :A 0.55
47.50  11.9 302 450   0:        :         :         *         :         :A 0.55
48.00  12.0 313 450   0:        :         :         :*        :         :A 0.50
48.50  12.1 323 450   0:        :         :         : *       :         :A 0.50
49.00  12.2 330 450   0:        :         :         :  *      :         :A 0.38
49.50  12.3 316 450   0:        :         :         :*        :         :D-0.70
50.00  12.4 302 450   3:        :         :         *         :         :D-0.70
50.50  12.5 286 450   3:        :         :       * :         :         :D-0.70
51.00  12.6 270 450   3:        :         :      *  :         :         :D-0.70
51.50  12.7 253 450   3:        :         :    *    :         :         :D-0.70
52.00  12.8 234 450   3:        :         :  *      :         :         :D-0.70
52.50  12.9 214 450   3:        :         :*        :         :         :D-0.70
53.00  13.1 191 191 C 3:        :        *:         :         :         :D-0.70
53.50  13.2 191 191 C 3:        :        *:         :         :         :C 0.00
54.00  13.4 211 450   3:        :         :*        :         :         :A 0.61
54.50  13.5 227 450   3:        :         : *       :         :         :A 0.56
55.00  13.6 243 450   3:        :         :   *     :         :         :A 0.56
55.50  13.8 257 450   3:        :         :    *    :         :         :A 0.56
```

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56.00  13.9 269 450   3:         :         :     *   :         :         :A 0.49
56.50  14.0 251 450   3:         :         :    *    :         :         :D-0.70
57.00  14.1 233 450   3:         :         :  *      :         :         :D-0.70
57.50  14.3 212 450   3:         :         :*        :         :         :D-0.70
58.00  14.4 190 450   3:         :        *:         :         :         :D-0.70
58.50  14.6 164 450   3:         :     *   :         :         :         :D-0.70
59.00  14.8 134 450   3:         :  *      :         :         :         :D-0.70
59.50  15.0  95 450   3:        *:         :         :         :         :D-0.70
60.00  17.7   0   0   3:STATION  :         :         :         :         :S-0.70
60.50  18.3  97 450   0:        *:         :         :         :         :A 0.74
61.00  18.5 136 450   0:         :  *      :         :         :         :A 0.70
61.50  18.7 165 450   0:         :     *   :         :         :         :A 0.68
62.00  18.9 189 450   0:         :       * :         :         :         :A 0.65
62.50  19.1 210 293 C 0:         :         :*        :         :         :A 0.65
63.00  19.2 228 293 C 0:         :         : *       :         :         :A 0.60
63.50  19.3 244 293 C 0:         :         :   *     :         :         :A 0.60
64.00  19.4 259 293 C 0:         :         :    *    :         :         :A 0.60
64.50  19.5 273 293 C 0:         :         :      *  :         :         :A 0.55
65.00  19.7 286 450   0:         :         :       * :         :         :A 0.55
65.50  19.8 298 399 C 0:         :         :        *:         :         :A 0.55
66.00  19.9 310 399 C 0:         :         :         :*        :         :A 0.55
66.50  20.0 314 399 C 0:         :         :         :*        :         :A 0.23
67.00  20.1 300 300 R 0:         :         :         *         :         :D-0.70
67.50  20.2 300 300 R 0:         :         :         *         :         :C 0.00
68.00  20.3 300 300 R 0:         :         :         *         :         :C 0.00
68.50  20.4 300 300 R 0:         :         :         *         :         :C 0.00
69.00  20.5 300 300 R 0:         :         :         *         :         :C 0.00
69.50  20.5 311 450   0:         :         :         :*        :         :A 0.55
70.00  20.6 321 450   0:         :         :         : *       :         :A 0.50
70.50  20.7 331 450   0:         :         :         :  *      :         :A 0.50
71.00  20.8 341 450   0:         :         :         :   *     :         :A 0.50
71.50  20.9 350 450   0:         :         :         :    *    :         :A 0.50
72.00  21.0 359 450   0:         :         :         :    *    :         :A 0.50
72.50  21.1 367 450   0:         :         :         :     *   :         :A 0.45
73.00  21.2 375 450   0:         :         :         :      *  :         :A 0.45
73.50  21.2 383 450   0:         :         :         :       * :         :A 0.45
74.00  21.3 390 450   0:         :         :         :        *:         :A 0.45
74.50  21.4 398 450   0:         :         :         :        *:         :A 0.45
75.00  21.5 405 450   0:         :         :         :         *         :A 0.45
75.50  21.5 411 450   0:         :         :         :         :*        :A 0.35
76.00  21.6 416 450   0:         :         :         :         :*        :A 0.35
76.50  21.7 410 450   0:         :         :         :         :*        :D-0.38
77.00  21.8 399 399 C 0:         :         :         :        *:         :D-0.70
77.50  21.8 399 399 C 0:         :         :         :        *:         :C 0.00
78.00  21.9 399 399 C 0:         :         :         :        *:         :C 0.00
78.50  22.0 399 399 C 0:         :         :         :        *:         :C 0.00
79.00  22.1 406 450   0:         :         :         :         *         :A 0.45
79.50  22.1 398 450   0:         :         :         :        *:         :D-0.49
80.00  22.2 387 450  -2:         :         :         :       * :         :D-0.70
80.50  22.3 375 450  -2:         :         :         :      *  :         :D-0.70
81.00  22.4 363 450  -2:         :         :         :     *   :         :D-0.70
81.50  22.5 350 350 C-2:         :         :         :    *    :         :D-0.70
82.00  22.5 350 350 C-2:         :         :         :    *    :         :C 0.00
82.50  22.6 350 350 C-2:         :         :         :    *    :         :C 0.00
83.00  22.7 350 350 C-2:         :         :         :    *    :         :C 0.00
83.50  22.8 350 350 C-2:         :         :         :    *    :         :C 0.00
84.00  22.9 362 399 C-2:         :         :         :     *   :         :A 0.66
84.50  23.0 372 399 C-2:         :         :         :      *  :         :A 0.61
85.00  23.0 383 399 C-2:         :         :         :       * :         :A 0.61
85.50  23.1 393 399 C 0:         :         :         :        *:         :A 0.61
```

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 86.00  23.2 399 399 C 0:        :         :         :        *:         :A 0.36
 86.50  23.3 406 450   0:        :         :         :         *         :A 0.45
 87.00  23.3 412 450   0:        :         :         :         :*        :A 0.35
 87.50  23.4 417 450   0:        :         :         :         :*        :A 0.35
 88.00  23.5 423 450   0:        :         :         :         : *       :A 0.35
 88.50  23.6 428 450   0:        :         :         :         : *       :A 0.35
 89.00  23.6 433 450   0:        :         :         :         :  *      :A 0.35
 89.50  23.7 438 450   0:        :         :         :         :  *      :A 0.35
 90.00  23.8 444 450   0:        :         :         :         :   *     :A 0.35
 90.50  23.8 449 450 C 0:        :         :         :         :   *     :A 0.35
 91.00  23.9 450 450 C 0:        :         :         :         :    *    :A 0.06
 91.50  24.0 450 450   0:        :         :         :         :    *    :C 0.00
 92.00  24.0 442 450   0:        :         :         :         :   *     :D-0.51
 92.50  24.1 432 450   0:        :         :         :         :  *      :D-0.70
 93.00  24.2 421 450   0:        :         :         :         : *       :D-0.70
 93.50  24.2 410 450   0:        :         :         :         :*        :D-0.70
 94.00  24.3 399 399 C 0:        :         :         :        *:         :D-0.70
 94.50  24.4 399 399 C 0:        :         :         :        *:         :C 0.00
 95.00  24.5 406 450   0:        :         :         :         *         :A 0.45
 95.50  24.5 410 450   0:        :         :         :         :*        :A 0.25
 96.00  24.6 399 399 C 0:        :         :         :        *:         :D-0.70
 96.50  24.7 399 399 C 0:        :         :         :        *:         :C 0.00
 97.00  24.8 399 399 C 0:        :         :         :        *:         :C 0.00
 97.50  24.8 406 450   0:        :         :         :         *         :A 0.45
 98.00  24.9 412 450   0:        :         :         :         :*        :A 0.35
 98.50  25.0 417 450   0:        :         :         :         :*        :A 0.35
 99.00  25.1 423 450   0:        :         :         :         : *       :A 0.35
 99.50  25.1 428 450   0:        :         :         :         : *       :A 0.35
100.00  25.2 433 450   5:        :         :         :         :  *      :A 0.35
100.50  25.3 432 450   5:        :         :         :         :  *      :D-0.10
101.00  25.3 421 450   5:        :         :         :         : *       :D-0.70
101.50  25.4 410 450   5:        :         :         :         :*        :D-0.70
102.00  25.5 399 399 C 5:        :         :         :        *:         :D-0.70
102.50  25.6 399 399 C 5:        :         :         :        *:         :C 0.00
103.00  25.6 399 399 C 5:        :         :         :        *:         :C 0.00
103.50  25.7 403 450   5:        :         :         :         *         :A 0.26
104.00  25.8 406 450   5:        :         :         :         *         :A 0.16
104.50  25.9 408 450   5:        :         :         :         *         :A 0.16
105.00  25.9 411 450   5:        :         :         :         :*        :A 0.16
105.50  26.0 413 450   5:        :         :         :         :*        :A 0.16
106.00  26.1 416 450   5:        :         :         :         :*        :A 0.16
106.50  26.1 418 450   5:        :         :         :         :*        :A 0.16
107.00  26.2 421 450   5:        :         :         :         : *       :A 0.16
107.50  26.3 423 450   5:        :         :         :         : *       :A 0.16
108.00  26.4 425 450   5:        :         :         :         : *       :A 0.16
108.50  26.4 428 450   0:        :         :         :         : *       :A 0.16
109.00  26.5 433 450   0:        :         :         :         :  *      :A 0.35
109.50  26.6 438 450   0:        :         :         :         :  *      :A 0.35
110.00  26.6 443 450   0:        :         :         :         :   *     :A 0.35
110.50  26.7 449 450   0:        :         :         :         :   *     :A 0.35
111.00  26.8 450 450   0:        :         :         :         :    *    :A 0.06
111.50  26.8 450 450   0:        :         :         :         :    *    :C 0.00
112.00  26.9 450 450   0:        :         :         :         :    *    :C 0.00
112.50  27.0 450 450   0:        :         :         :         :    *    :C 0.00
113.00  27.0 450 450   0:        :         :         :         :    *    :C 0.00
113.50  27.1 450 450   0:        :         :         :         :    *    :C 0.00
114.00  27.2 444 450   0:        :         :         :         :   *     :D-0.37
114.50  27.2 434 450   0:        :         :         :         :  *      :D-0.70
115.00  27.3 423 450   0:        :         :         :         : *       :D-0.70
115.50  27.4 412 450   0:        :         :         :         :*        :D-0.70
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116.00  27.4 401 450   0:        :         :         :         *         :D-0.70
116.50  27.5 390 450   0:        :         :         :        *:         :D-0.70
117.00  27.6 378 450   0:        :         :         :      *  :         :D-0.70
117.50  27.7 366 450   0:        :         :         :     *   :         :D-0.70
118.00  27.8 353 450   0:        :         :         :    *    :         :D-0.70
118.50  27.9 340 450   0:        :         :         :   *     :         :D-0.70
119.00  27.9 326 450   0:        :         :         : *       :         :D-0.70
119.50  28.0 312 450   0:        :         :         :*        :         :D-0.70
120.00  28.1 297 450   0:        :         :        *:         :         :D-0.70
120.50  28.2 282 450   0:        :         :       * :         :         :D-0.70
121.00  28.3 265 450   0:        :         :     *   :         :         :D-0.70
121.50  28.5 248 450   0:        :         :   *     :         :         :D-0.70
122.00  28.6 229 450   0:        :         : *       :         :         :D-0.70
122.50  28.7 208 450   0:        :         *         :         :         :D-0.70
123.00  28.9 185 185 C 0:        :       * :         :         :         :D-0.70
123.50  29.0 185 185 C 0:        :       * :         :         :         :C 0.00
124.00  29.2 206 450   0:        :         *         :         :         :A 0.65
124.50  29.3 224 450   0:        :         : *       :         :         :A 0.60
125.00  29.5 241 450   0:        :         :   *     :         :         :A 0.60
125.50  29.6 257 450   0:        :         :    *    :         :         :A 0.60
126.00  29.7 265 450   0:        :         :     *   :         :         :A 0.35
126.50  29.8 248 450   0:        :         :   *     :         :         :D-0.70
127.00  29.9 229 450   0:        :         : *       :         :         :D-0.70
127.50  30.1 208 450   0:        :         *         :         :         :D-0.70
128.00  30.2 185 185 C 0:        :       * :         :         :         :D-0.70
128.50  30.4 164 185 C 0:        :     *   :         :         :         :D-0.55
129.00  30.6 134 450   0:        :  *      :         :         :         :D-0.70
129.50  30.9  95 450   0:       *:         :         :         :         :D-0.70
130.00  34.5   0   0 R 0:STATION :         :         :         :         :S-0.70
130.50  35.1 100 150 R 0:        *         :         :         :         :A 0.78
131.00  35.3 138 150 R 0:        :  *      :         :         :         :A 0.70
131.50  35.5 150 150 R 0:        :    *    :         :         :         :A 0.26
132.00  35.7 150 150 R 0:        :    *    :         :         :         :C 0.00
132.50  35.9 150 150 R 0:        :    *    :         :         :         :C 0.00
133.00  36.1 150 150 R 0:        :    *    :         :         :         :C 0.00
133.50  36.3 176 450   0:        :      *  :         :         :         :A 0.68
134.00  36.5 199 450   0:        :        *:         :         :         :A 0.65
134.50  36.6 202 450   0:        :         *         :         :         :A 0.10
135.00  36.8 178 178 C 0:        :      *  :         :         :         :D-0.70
135.50  37.0 178 178 C 0:        :      *  :         :         :         :C 0.00
136.00  37.1 178 178 C 0:        :      *  :         :         :         :C 0.00
136.50  37.3 200 450   0:        :         *         :         :         :A 0.65
137.00  37.4 220 247 C 0:        :         : *       :         :         :A 0.65
137.50  37.6 206 247 C 0:        :         *         :         :         :D-0.47
138.00  37.7 183 247 C 0:        :       * :         :         :         :D-0.70
138.50  37.9 156 156 C 0:        :    *    :         :         :         :D-0.70
139.00  38.1 156 156 C 0:        :    *    :         :         :         :C 0.00
139.50  38.3 176 450   0:        :      *  :         :         :         :A 0.51
140.00  38.5 148 148 C 0:        :   *     :         :         :         :D-0.70
140.50  38.6 175 221 C 0:        :      *  :         :         :         :A 0.68
141.00  38.8 198 221 C 0:        :        *:         :         :         :A 0.65
141.50  38.9 218 450   0:        :         :*        :         :         :A 0.65
142.00  39.1 235 450   0:        :         :  *      :         :         :A 0.60
142.50  39.2 247 247 C 0:        :         :   *     :         :         :A 0.45
143.00  39.3 247 247 C 0:        :         :   *     :         :         :C 0.00
143.50  39.4 241 450   0:        :         :   *     :         :         :D-0.25
144.00  39.6 221 221 C 0:        :         : *       :         :         :D-0.70
144.50  39.7 221 221 C 0:        :         : *       :         :         :C 0.00
145.00  39.9 206 221 C 0:        :         *         :         :         :D-0.49
145.50  40.0 183 221 C 0:        :       * :         :         :         :D-0.70
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146.00  40.2 156 156 C 0:        :    *    :         :         :         :D-0.70
146.50  40.4 156 156 C 0:        :    *    :         :         :         :C 0.00
147.00  40.6 176 450   0:        :      *  :         :         :         :A 0.51
147.50  40.7 148 148 C 0:        :   *     :         :         :         :D-0.70
148.00  40.9 175 450   0:        :      *  :         :         :         :A 0.68
148.50  41.1 164 450   0:        :     *   :         :         :         :D-0.29
149.00  41.3 134 450   0:        :  *      :         :         :         :D-0.70
149.50  41.6  95 450   0:       *:         :         :         :         :D-0.70
150.00  42.2   0 450   0:STATION :         :         :         :         :S-0.70

--------------------------------------------------------------------------------
The system selected is: MAGLEV Transrapid 07 having  3 sections and 240 seats

Total Distance:   150.00 km,    Total Travel Time:    42.19 min

There are  2 intermediate stations, Avg dwelling time per station:  2.50 min

Average Speed (excluding dwelling time at stations):  241.98 km/hr

Travel at max speed of 450.0 km/hr   for:  0.668 minutes,    and:  5.000 km

Travel at   0 to 100 km/hr for:   3.50 km ( 2.3%)  and   8.29 minutes (22.3%)
Travel at 101 to 200 km/hr for:  28.50 km (19.0%)  and  11.11 minutes (29.9%)
Travel at 201 to 300 km/hr for:  47.50 km (31.7%)  and  11.46 minutes (30.8%)
Travel at 301 to 400 km/hr for:  42.00 km (28.0%)  and   7.31 minutes (19.7%)
Travel at 401 to 500 km/hr for:  28.50 km (19.0%)  and   4.03 minutes (10.8%)

Total Energy Consumption : 1740.94 KWH             Route Length:  150.00 km
Average Energy Consumption : 11.61 KWH/km    or    4.836 KWH/100km/pass-seat

Speed limits (Vmax):  C=Curve, N=Noise, B=Bridge, S=Station, T=Tunnel D=Dummy
Acceleration (m/s2):  A=Accceleration,  D=Deceleration,   C=Constant,  S=Stop
--------------------------------------------------------------------------------
```

# APPENDIX E

# TECHNICAL DATA RELATED TO THE TRANSRAPID MAGLEV SYSTEM OBTAINED FROM THE MANAGING DIRECTOR OF TRANSRAPID TESTING FACILITY IN GERMANY

*Versuchs- und
Planungsgesellschaft
für Magnetbahnsysteme
m.b.H.*

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Mr.
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University of Florida
Civil Engineering Department
346 Weil Hall, Gainesville

Fl 32611 USA

| Ihr Zeichen | Ihre Nachricht vom | Unsere Nachricht vom | Unser Zeichen | Tel.-Durchwahl | Datum |
|---|---|---|---|---|---|
|  |  |  | kop | - 39 | 29.07.92 |

Dear Mr. Nassar,

please apologize our late reply to your letter dated march 12, 1992, but the decision of the German government to take the TRANSRAPID in consideration for the specific route between Hamburg and Berlin requires intensive analysis and detailed evaluation work.

In accordance with Mr. Steinmetz (IABG), our deputy of the test site, we herewith return your questionaire and some additional explanations.

We hope the above given facts and figures are helpful for your presentation.

Sincerely

Kokott

Polifka

i.A. Kokott

Sitz der Gesellschaft: München
Register: Amtsgericht München, HRB 68 261

Geschäftsführer: Dipl.-Ing. Fritz Polifka
Dipl.-Kfm. Rainer Ribbentrop

Vorsitzender des Aufsichtsrats:
Dipl.-Ing. Roland Heinisch

**FORM FILLED BY:**
NAME: F. Polifka , J. Kokott
POSITION: Manager , Engineer
COMPANY: MVP
ADDRESS: Landsbergerstr. 76 D 8000 München 2
PHONE: 089/ 50067-0

| | TRANSRAPID-07 SPEED - km/h | MAXIMUM ACCELERA. | COMFORTABLE ACCELERATION | MAXIMUM DECELERA. | COMFORTABLE DECELERATION |
|---|---|---|---|---|---|
| 1. | 0-100 | | | | |
| | 100-200 | | | | |
| | 200-300 | see enclosed pages | | -0,9 m/s² | -0,7 m/s² |
| | 300-400 | | | | |
| | 400-500 | | | | |

2. Maximum Superelevation: 12°

3. Maximum Unbalanced Superelevation: 4,5°/5,5° (standard/exception)

4. Maximum Total Superelevation: 16,5°/17,5° (standard/exception)

5. Maximum lateral acceleration: 0,8/1,0(standard/exception) m/s²

6. Maximum acceleration/deceleration rates: +1,0 / -1,5 m/s²

7. Maximum Speed: 400/500 km/h Maximum Revenue Speed: see enclosed pages km/h

8. Maximum grade: 10% Grade Length: no restrictions

9. Formulas used to compute the impact of grade on acceleration/decel.:

see enclosed pages

10. Minimum Radius: [m]

| Speed | minimum radius |
|---|---|
| Speed=100 km/h | minimum radius= 400/400 |
| Speed=200 km/h | minimum radius= 1050/1000 |
| Speed=300 km/h | minimum radius= 2400/2250 |
| Speed=400 km/h | minimum radius= 4250/4000 |
| Speed=500 km/h | minimum radius= 6650/6250 |

11. Formulas used to compute maximum speed on curves:

see enclosed pages

**Return Address:**
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University of Florida
Civil Engineering Department
346 Weil Hall, Gainesville, Fl 32611, USA

Maximum acceleration (m/s²)

| Length of train | 2 - 6 sections | 7 - 8 sections | 9 - 10 sections |
|---|---|---|---|
| Speed (km/h) | | | |
| 0 - 100 | 0,80 - 0,70 | 0,77 - 0,67 | 0,77 - 0,67 |
| 100 - 200 | 0,70 - 0,66 | 0,67 - 0,65 | 0,67 - 0,63 |
| 200 - 300 | 0,66 - 0,58 | 0,65 - 0,58 | 0,63 - 0,45 |
| 300 - 400 | 0,58 - 0,45 | 0,58 - 0,20 | 0,45 - 0,10* |
| 400 - 500 | 0,45 - 0,15 | --- | --- |

Comfortable acceleration (m/s²)

| Length of train | 2 - 6 sections | 7 - 8 sections | 9 - 10 sections |
|---|---|---|---|
| Speed (km/h) | | | |
| 0 - 100 | 0,70 | 0,65 | 0,65 |
| 100 - 200 | 0,65 | 0,60 | 0,60 |
| 200 - 300 | 0,55 | 0,55 | 0,55 - 0,45 |
| 300 - 400 | 0,45 | 0,45 - 0,2 | 0,45 - 0,10* |
| 400 - 500 | 0,15 | --- | --- |

* = up to v = 350 km/h

| | |
|---|---|
| 1 section: | Length = 25 m<br>Weight = 60.000 kg (incl. max. load) |

The comfortable acceleration is used under normal operation conditions.

The maximum acceleration is needed to regulate the operation and to keep a late train in schedule.

The same explications apply to maximum/comfortable deceleration.

Further explanations

3. Maximum unbalanced superelevation is the difference of the superelevation deficieny between lateral acceleration 0,8 m/s² (standard) with 12° superelevation and lateral acceleration 0,0 m/s² as well as between lat. acc. 1,0 m/s² (exception) with 12° superelevation and lat. acc. 0,0 m/s².

4. Sums of 2. and 3. for the superelevations (theoretical dates) with balanced accelerations (0,0 m/s²) for the standard case (0,8 m/s² --> 0,0 m/s²) and the exception (1,0 m/s² --> 0,0 m/s²).

6. Maximum acceleration rate may occur under worst-case-conditions in case of serious misfunctions of energy supply and linear motor. In this case the safety systems stop the energy supply at once.

   Maximum deceleration rate is given under emergency brake conditions.

   Under normal operation conditions there is no max. acceleration/deceleration.

7. A maximum speed of 400 km/h can be planed for every length of train, except 9 and 10 section-trains (350 km/h). A maximum speed of 500 km/h can be reached by 2 - 6 section-trains.

   We interpret your question about "max. revenue speed" als "commercial speed".

   The commercial speed (average voyaging speed) is calculated with the shortest travelling time between the stations plus 5 % plus times for the train stops (except first and last station). It depends on the length of the track, number of stations and the track alignement.

8. Because of the linear motor layout there are theoretically no restrictions for the length of grades, practically the lengths are restricted by the topography of the landscape.

9. The impact of grade is compensated with a special linear motor layout, so that you keep a minimum acceleration rate of 0,15 $m/s^2$ in every case, or more if needed and the grade is less than 10 %.

   For deceleration you get (if necessary) the same rates as mentioned under item 1 because of the special linear motor layout and the resistance of the riding forces.

10. Minimum radius = first radius/second radius
    first radius is used under normal alignement conditions, (lateral acceleration = 0,8 $m/s^2$),
    second radius is used exceptionally under difficult alignement conditions (lateral acceleration = 1,0 $m/s^2$)
    V = 100 km/h: first radius with superelevation 6,5°
    second radius with superelevation 5,5°
    V = 200 - 500 km/h: each radius with superelevation 12°

11.

$$V = \sqrt{\frac{R\,(a + g \sin\alpha\ \ )}{\cos \alpha}}$$

R = radius (m)
$\alpha$ = superelevation (°)
g = 9,81 (m/s2)
a = lateral acceleration (m/s2)
v = velocity (m/s)

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*für Magnetbahnsysteme*
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| Ihr Zeichen | Ihre Nachricht vom | Unsere Nachricht vom | Unser Zeichen | Tel.-Durchwahl | Datum |
|---|---|---|---|---|---|
| | | | koz | 39 | 05.11.92 |

Dear Mr. Nassar,

enclosed you will find some figures you asked for in your last letter dated Oct. 11th ,1992.

For it is not possible to give a simple energy modeling equation (we use a computer program with a lot of input datas/parameters) we worked out some specific figures. For the noise emissions we can tell you the results of the measurements that were evaluated on our test site in Emsland.

Sincerely

(Polifka)　　　　(I.A. Kokott)

**Relationship between grades, tractive power and acceleration:**

$a_x$ = $(F_x - F_{wid}) / m$
$a_x$ = longitudinal acceleration [m/s$^2$]
$F_x$ = tractive force kN]
$F_{wid}$ = riding forces kN]
m = mass of trainset [kg]

$F_x$ is the product of the specific motordate per section [N/A], the number of sections [ - ] and the stator current [kA].

$F_{wid}$ is the sum of aerodynamic forces, forces of the linear generator, forces of the traction- and guiding magnets and forces of the grades (= m . g . sinα).

If you take the actual max. stator current of 1,5 kA and a mass of 55.000 kg per section ( ~ 50 % load) into account, you get the following accelerations:

| V [km/h] | grade [%] | acceleration [m/s$^2$] |
|---|---|---|
| 100 | 2,5 | 0,7 |
| | 5,0 | 0,4 |
| | 9,5 | 0,0 |
| | 10,0 | - 0,04 |
| 200 | 2,5 | 0,7 |
| | 5,0 | 0,4 |
| | 9,3 | 0,0 |
| | 10,0 | - 0,07 |
| 300 | 2,5 | 0,6 |
| | 5,0 | 0,4 |
| | 8,7 | 0,0 |
| | 10,0 | - 0,1 |
| 400 | 2,5 | 0,5 |
| | 5,0 | 0,3 |
| | 7,6 | 0,0 |
| | 10,0 | - 0,2 |

If you compare the above given figures with the figures of the acceleration in our last letter there is no inconsistence, because the accelerations in this paper between 0 - 100 km/h rangeing from 1,0 - 0,9 m/s$^2$ (without grades) come about with the maximum stator current of 1,5 kA, the accelerations in our last letter come about with a reduced stator current because of energy-saving aspects.

As the figures show furtheron, you can't keep an acceleration of 0,15 m/s$^2$ in higher grades but you can keep a constant velocity in grades between 8 - 9 %.

A decrease of velocity under maximum grades seems to be acceptable within our actuel motorlayouts, because other high-speed ground transportation systems show the same effect even under much more moderate grades (3,5 %).

Nevertheless there is the possibility for Transrapid to reach an acceleration of 0,15 m/s$^2$ in maximum grades if necessary. Therefore the max. stator current must be increased what is possible with very short linearmotor-sections and more or stronger propulsion units. That would increase the costs for the propulsion hardware and the energy consumption. For this case we didn't yet work out detailed figures, because there is only a very small advantage for the commercial speed.

**Relationship between lateral acceleration and unbalanced superelevation:**

The Transrapid-System does not deal with the unbalanced superelevation. We accept instead a lateral acceleration of 0,8/1,0 m/s$^2$ for the track alignement, as mentioned in our last letter.

The figures can be worked out with the formulas:

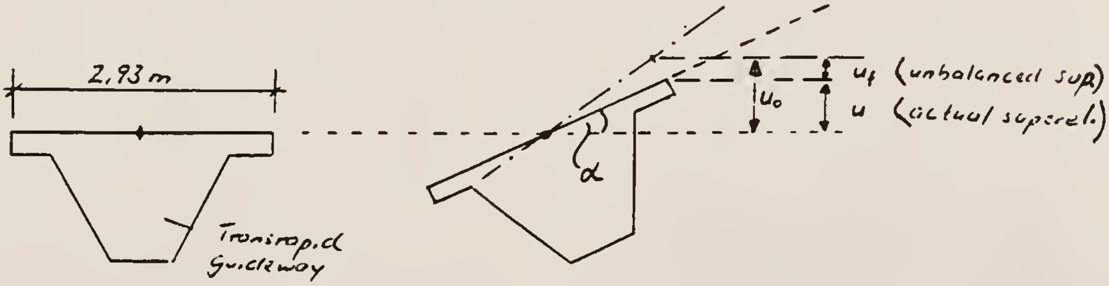
lateral acceleration $a_l = \frac{V^2 \cdot \cos\alpha}{R} - g \cdot \sin\alpha$

velocity $v = \sqrt{\frac{R\,(a_l + g\,\sin\alpha)}{\cos\alpha}}$

$a_l$ [m/s$^2$]
$v$ [m/s]
$R$ [m]
$g = 9{,}81$ m/s$^2$

the whole trainset is assumed to be a mass-point

The figure $a_l$ ist caused by the unbalanced superelevation.



for example:

$\alpha = 12^o \Rightarrow u = \sin\alpha \cdot 146{,}5$ cm $= 30{,}5$ cm

$R = 4250$ m, $v = 400$ km/h $\Rightarrow a_l = 0{,}8$ m/s$^2$

$a_l = 0{,}0 \Rightarrow \alpha = 16{,}5^o \Rightarrow u_o = 41{,}6$ cm (V, R as above)

$u_f = u_o - u = 11{,}1$ cm

**Energy consumption:**

| Vmax [km/h] | length of train [sections] | | | |
|---|---|---|---|---|
| | 3 | 5 | 6 | 8 |
| 100 | 6,6 | 10,9 | 13,1 | 17,1 |
| 200 | 7,7 | 12,4 | 14,7 | 20,3 |
| 300 | 10,7 | 17,0 | 20,2 | 28,5 |
| 400 | 15,8 | 24,7 | 29,3 | 41,3 |

Energy consumption [kWh/trainset and km]

The figures are calculated with a computer program under consideration of the specific riding forces, depending on lengths of the trains and velocity.

The calculation starts with v = 0, phase of acceleration, phase of constant riding (Vmax), phase of deceleration and ends with v = 0.

Mass of the train = 55.000 kg/section, $\eta$ = 0,9, length of the line = 300 km, grade = 0,0.

For comparisions with other transportation systems it is necessary to take the number of offered seats into consideration
(3/5/6/8 sections: 240/408/500/668 seats).

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| Ihr Zeichen | Ihre Nachricht vom | Unsere Nachricht vom | Unser Zeichen | Tel.-Durchwahl | Datum |
|---|---|---|---|---|---|
| | | | kob | -39 | 24.05.93 |

Dear Mr. Nassar,

enclosed you will find the answers to your letter dated Feb. 23, 1993. In order to save same extra time we refer in several answers to "Einsatzfelder neuer Schnellbahnsysteme" (short EFS) which you'll also find enclosed. (One version in german with grafics, one quick translation without grafics.)

Sincerely

Polifka

(Polifka)

Kokott

(i.A. Kokott)

1. - In opposite to trains Transrapid cannot tip over, neither with low velocity.

   - Experiences from the TVE-testsite show, that lateral accelerations about 1 $^{m}/s^{2}$ are not uncomfortable. It's more important to keep the jerk low ($\dot{a}_l \leq 0,5$ $^{m}/s^{3}$).

   - Generally there are different trainsets on a railway track. Because of slow trains you cannot choose a high superelevation. That's a question of tipping over and of maintenance costs. The question of maintenance costs is the same with high velocity/large superelevation on special high-speed tracks.

   - Comfortable deceleration rates for Transrapid $\leq 0,7$ $^{m}/s^{2}$ (see letter dated 29.07.92)
     Comfortable deceleration rates for ICE about $\leq 0,6$ $^{m}/s^{2}$ (= max decel. as well).
     Enlarged deceleration for ICE under normal operation conditions are not possible, because of the contact between wheel and rail.

2. - Construction costs: see EFS page 29

   - Vertical accelerations: $+ 1,0$ $^{m}/s^{2}$ (↓), $-0,5$ $^{m}/s^{2}$ (↑)

3. - Energy consumption, noise level:see EFS page 32, 33

4. - Land requirement: see EFS page 31

   - Access road is not necessary

   - Minimum land requirement for Transrapid

     a) about 9 $m^{2}/m$ for double track (v 200) for elevated and on ground track including an extra distance of 0,6 m to the vehicles

     b) only the land for foundation of the elevated double track (about 25 $m^{2}$ every 25 m), if a) is not possible

   - The elevated track for railways ist about 80% more expensive than the elevated track for Transrapid because you have to calculate a bridge construction. (The above given figure of 80% is only for the bridge construction, the railway track is not included.)

5. - Operation and maintenance costs:see EFS, page 30

6. - Capital costs: see EFS, page 19

   - Operation and maintenance costs:
     Energie: about 40%
     Staff in stations: about 27% (including materials)
     Staff for cleaning and preparing of the vehicles: about 3% (including materials)
     Staff onboard the vehicles: about 13%
     Staff for maintenance of tracks and stations: about 13% (including materials)
     Staff for maintenance of the vehicles: about 4% (including materials)

   - The costs for the guideways are calculated as an optimum between height, foundation and girderlength.

     For the elevated track we will use a

     31 m-one-span-girder (concrete) and a

     48 m-two-span-girder (steel) for standard applications of the elevated track, (other lengths are as well possible for special applications.)

   - A reduction of the costs for the guideway is still expected because of automatical production. However the major advantages are to be found in the heigh quality standard of production and product and the low maintenance costs later on.

7. Advantages of Transrapid in brief

   - acceleration + high velocity -> short travelling times
   - same travelling time as ICE -> more stopovers for Transrapid possible
   - lower maintenance costs because of frictionlessnes
   - better alignement parameters -> lower construction costs under difficult topography conditions
   - maximum of safety and reliability because of automatical operation and supervision
   - maximum comfort for travellers because of a dense schedule (one train every 10 minutes)
   - low noise-emissions as well as low electrical and magnetic emissions and low land- and energy consumption

# APPENDIX F

# TECHNICAL DATA RELATED TO THE TGV HIGH-SPEED RAIL SYSTEM OBTAINED FROM THE FRENCH NATIONAL RAILWAYS (SNCF)

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Expéditeur (Fm) :

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75009 PARIS

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TELECOPIE (1) 40 16 64 44

Destinataire (To) :Mr.Fadi Emil NASSAR
UNIVERSITY OF FLORIDA

TELEPHONE
TELECOPIE :19 1 904 392 3394

DATE: 02/02/93
REF: DC/

PAGES

---

To: Mr Fadi Emil NASSAR

Fm: Mr Gabriel COURBEY

Date: 02 Feb. 1993

Je vous envoie, ce jour, par courrier, les documents TGV que vous m'avez demandés.

Best regards,

G. COURBEY

Translation from French:

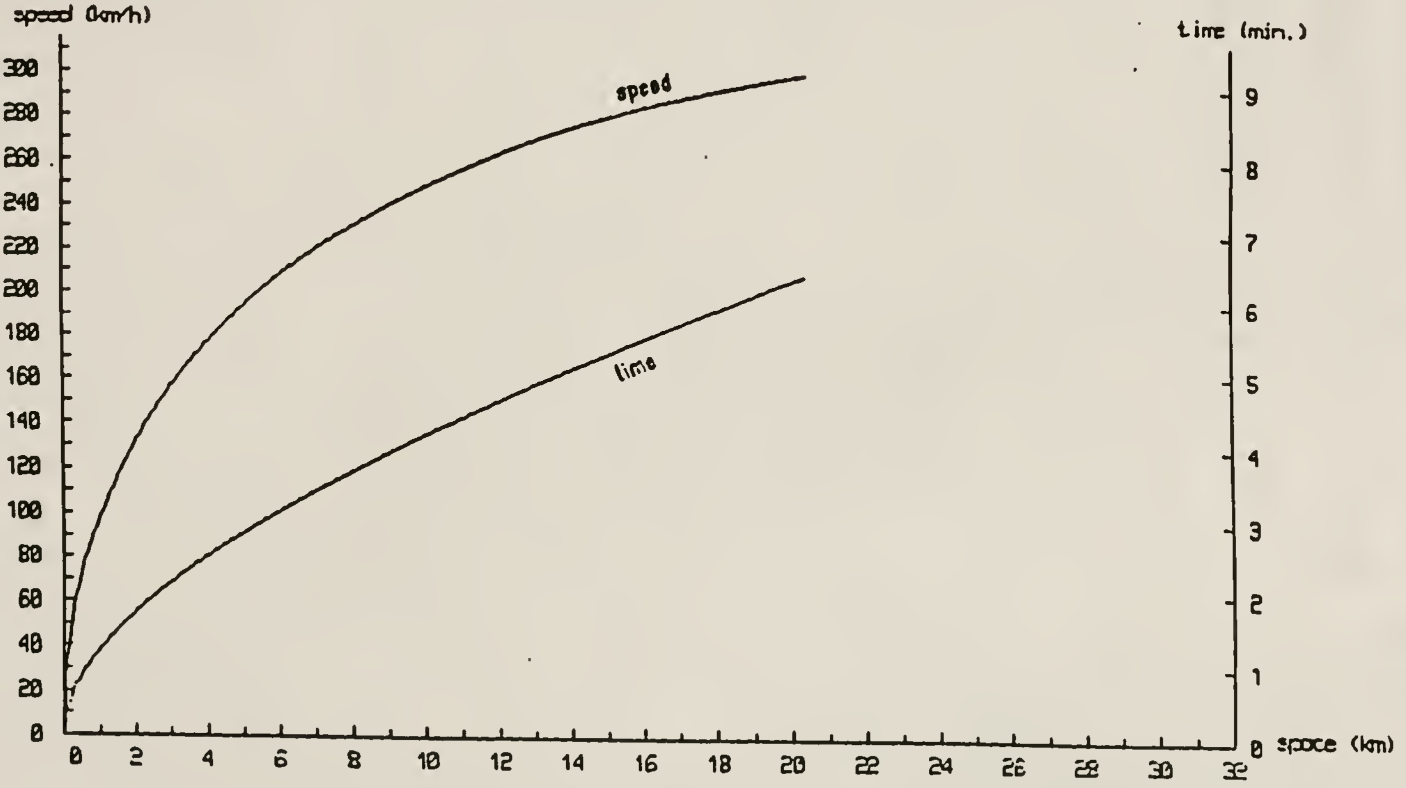
I'm sending you today by mail the documents related to the TGV that you have requested from me.

# ACCELERATION CURVE

Train reference: TGV-A M+10R+M LOAD

Mass of train: 490t          gradient (o/oo): 0.0

Resistance effort (daN): 295.000+(3.9200)V+(0.06240)V $^2$ with wind: 8 km/h

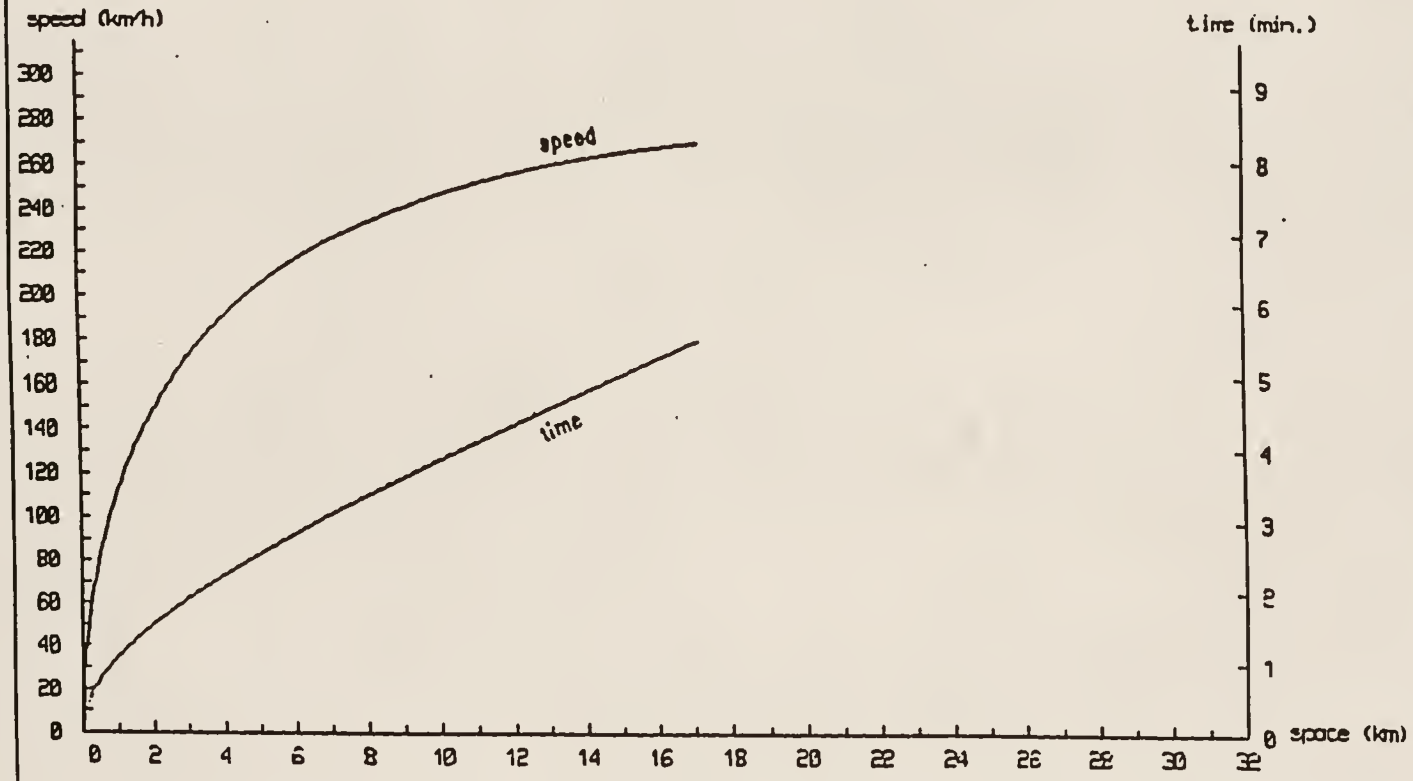


# ACCELERATION CURVE

Train reference: TGV-PSE M+8R+M LOAD

Mass of train: 418t gradient (o/oo): 0.0

Resistance effort (daN): 254.000+(3.3400)V+(0.05720)V ² with wind: 8 km/h

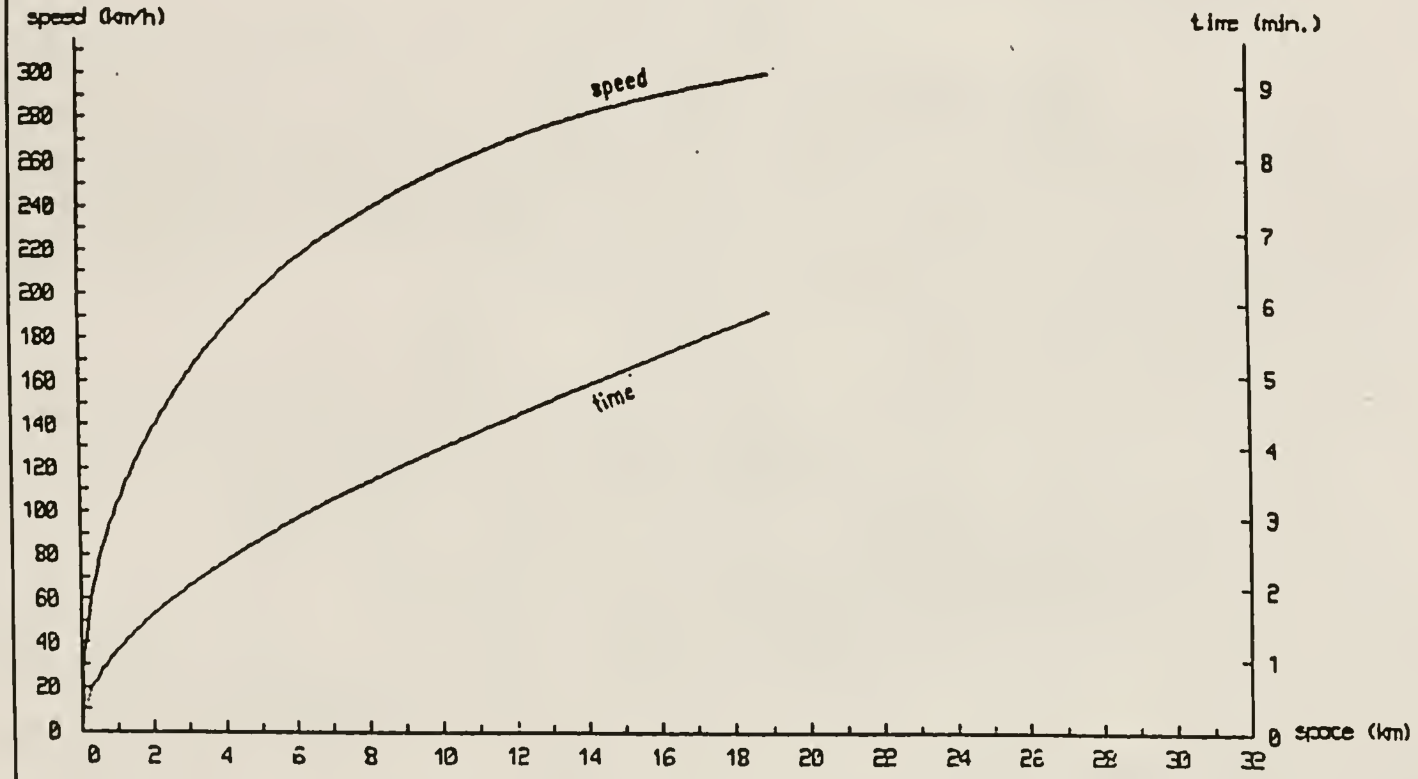


# ACCELERATION CURVE

Train reference: TGV-2N M+8R+M LOAD

Mass of train: 442t gradient (o/oo): 0.0

Resistance effort (daN): $261.000+(3.6300)V+(0.06700)V^2$ with wind: 8 km/h

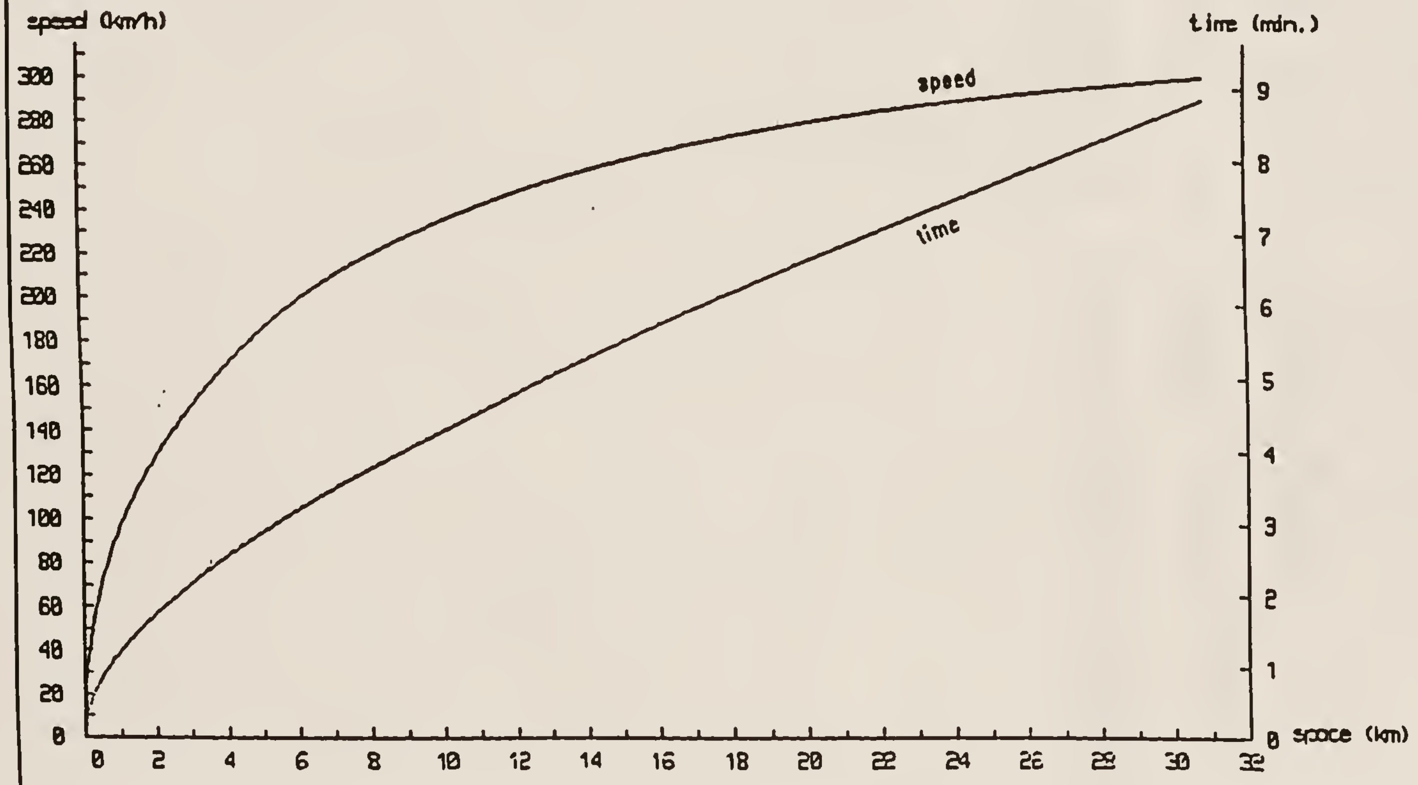


# ACCELERATION CURVE

Train reference: TMST M+18R+M LOAD

Mass of train: 816t gradient (o/oo): 0.0

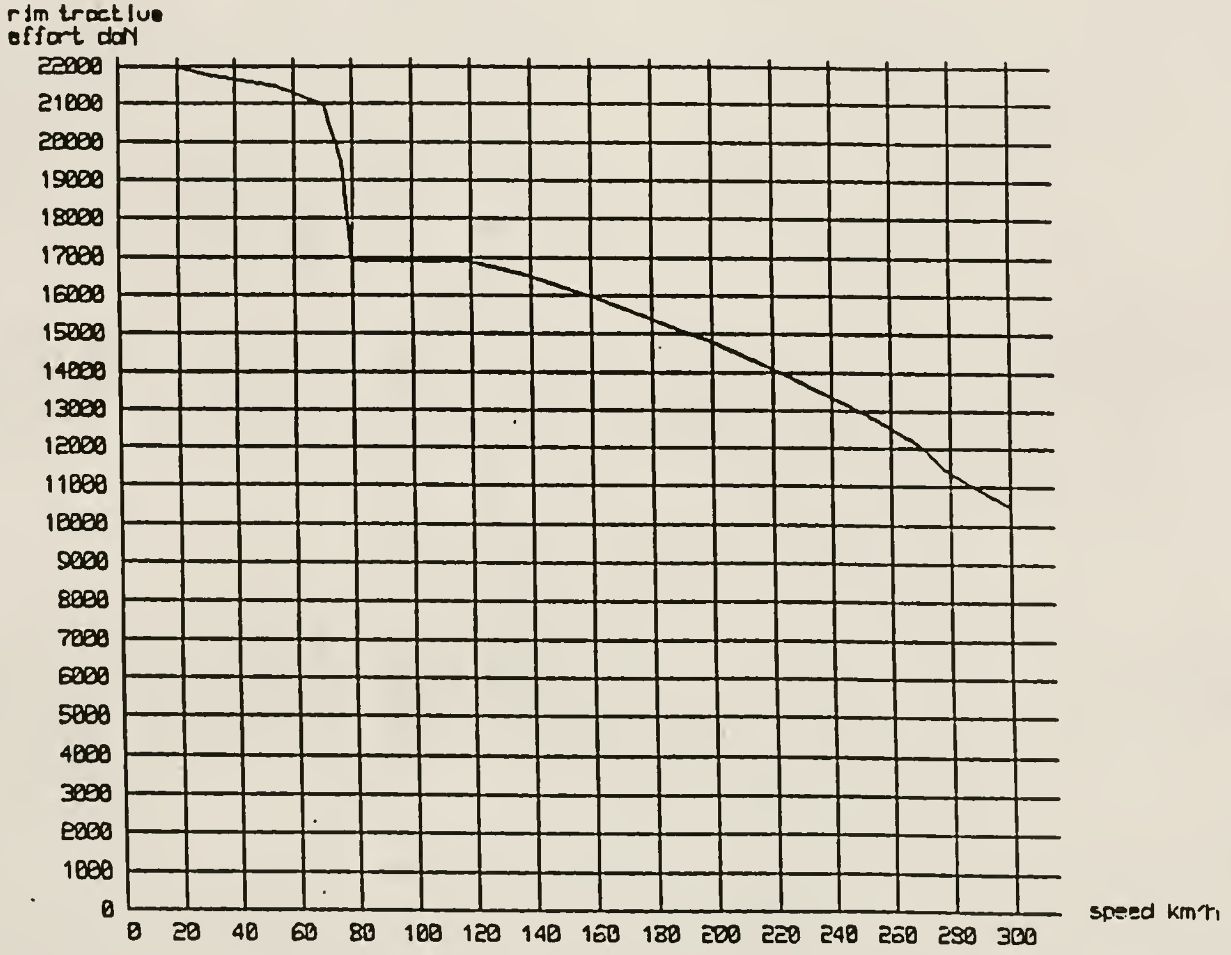
Resistance effort (daN): 482.000+(6.5300)V+(0.10500)$V^2$ with wind: 8 km/h

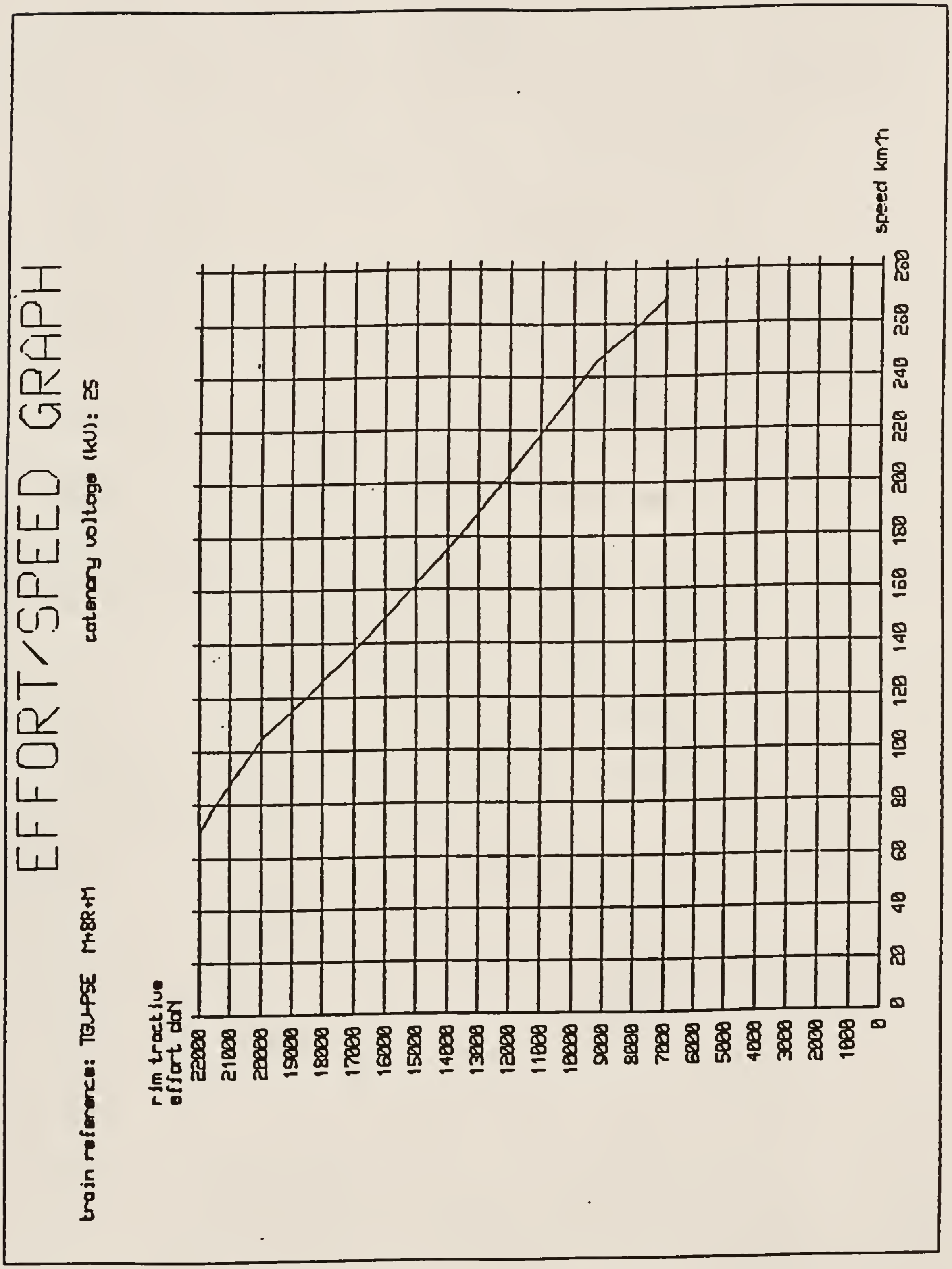


# EFFORT/SPEED GRAPH

train reference: TGV-A M+10R+M

catenary voltage (kV): 25



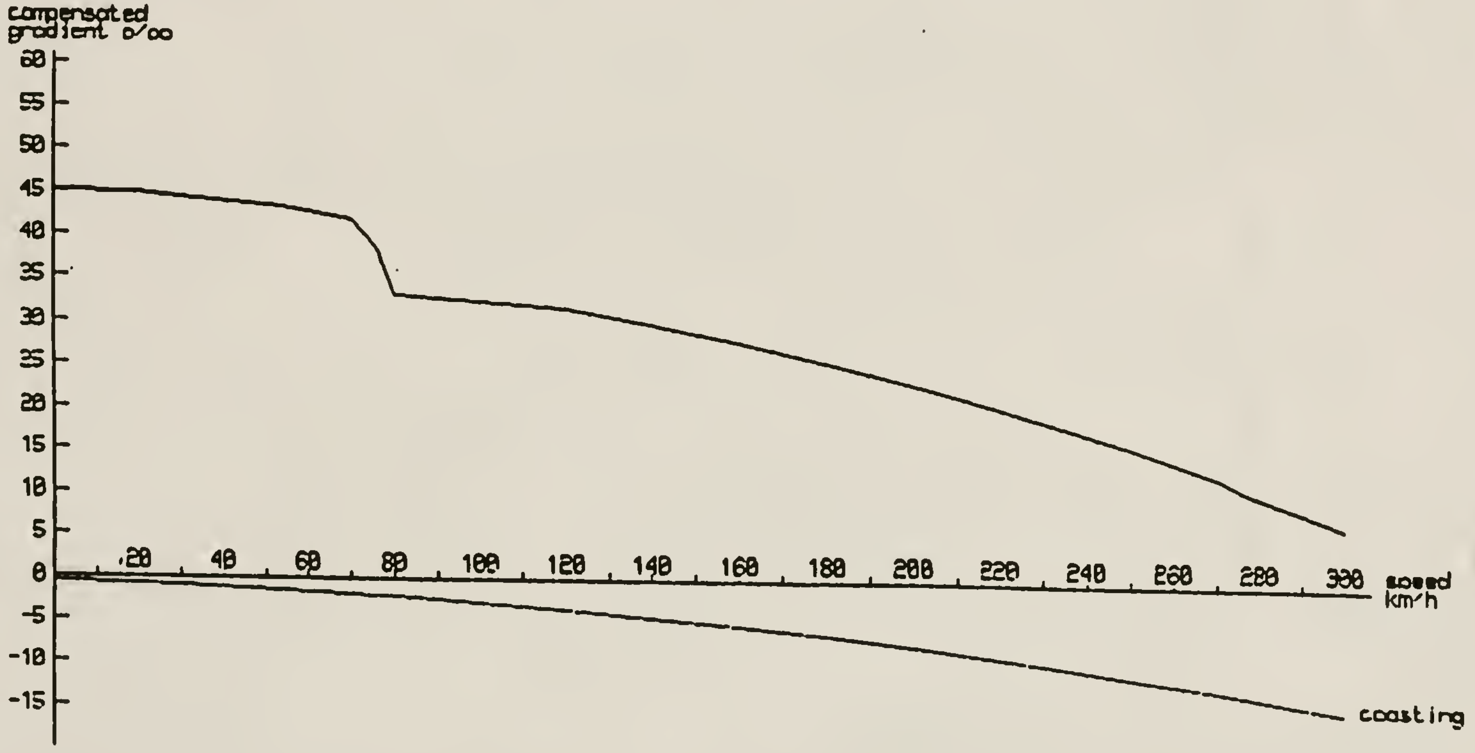

EFFORT/SPEED GRAPH
train reference: TGV-PSE M+8R+M
catenary voltage (kV): 25
rim tractive effort daN
22000
21000
20000
19000
18000
17000
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
speed km/h
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280

# GRADIENT/SPEED GRAPH

train reference: TGV-A  M+10R+M  LOAD

mass of train: 490t

Resistance effort (daN): 295.000+(3.9200)V+(0.06240)V² with wind: 8 km/h



# TGV-A POWER CAR DATA SHEET

MECHANICAL
Overall length : 22.15 m
Maximum width of body : 2.814 m
Maximum height above rail : 4.1 m
Weight : 67.8 t
Wheelbase of wheelsets in the bogie : 3 m
Distance between bogie pivot centres : 14 m
Number of motored axles : 4
Nominal diameter of wheels : 0.92 m
Max. axle load : 17 t
Type of power transmission : reduction gear, sliding cardan shaft and final drive
Gear ratio : 2.1894
Braking : (complementing dynamic brake) : 1 sintered metal shoe per wheel.

ELECTRICAL
Type of supply : single-phase AC, 25 kV, 50 Hz or 1.5 kV DC
Traction motors : 4, synchronous 3-phase, self-excited type
Continuous rating of motor : 11,000 kW (1,500 hp)
Power conversion : motors supplied from half-controlled inverters under single-phase AC supply ; from chopper under DC supply
Auxiliary equipment power scheme : 3-phase asynchronous motors supplied via GTO thyristor inverters from 500 V DC supply
Dynamic brake : rheostatic type developing 3/4 of maximum braking power.

# TRAINSET DATA SHEET

Formation : PwrCar + 10 Trailers + PwrCar
Length : 237.59 m (259.83 yds)
Weight (with normal load) : 490 t (metric)
Seating accommodations : 485 (116 + 11 tip-up seats in 1st Class 369 + 26 tip-up seats in 2nd Class)
Seats : All pile fabric, with individual pneumatic adjustment in 1st Class ; All fabric in 2nd Class.
Special interior arrangements : family, nursery, wheelchair compartments (+ special toilet for the handicapped),
galleys for "at the seat" meal service,
3 telephone booths, interior and exterior electronic signing.
Intercommunication gangway : doorless
Air conditioning : summer/winter dual flow
Starting tractive effort : 21,200 daN
Continuously rated tractive effort with 25 kV supply : 11,000 daN at 284 km/h
Continuous rating with 25 kV supply : 8,800 kW (12,000 hp)
One-hour rating with 25 kV supply : 10,400 kW (14,000 hp)
Continuous rating with 1.5 kV supply : 3,880 kW (5,300 hp)
Top speed in commercial service :
on new line : 300 km/h
on conventional line : 220 km/h
Time required to reach 300 km/h speed from standstill : 6 mn 30 s
Emergency stopping distance from 300 km/h speed : 3,300 m

# TGV-A TRAILER DATA SHEET

Overall length of middle trailers (R2-R9) : 18.700 m
Overall length of end trailers (R1-R10) : 21.845 m
Maximum height above rail : 3.480 m
Maximum width : 2.904 m
Height of floor above rail : 1.069 m
Bogies : intermediate trailer bogies, type Y237A, common to consecutive trailers and Y237B trailer bogies under ends of trailer rake
Distance between trailer bogie pivot centres : 18.7 m
Nominal diameter of wheels : 0.920 m
Secondary suspension : type SR10 pneumatic dampers with high lateral and vertical flexibility
Max. axle load : 17 t
Braking : solid steel discs with sintered metal linings
Price : approximately 70 million French francs.

| | **Paris-Sud-Est** | **Atlantique** |
|---|---|---|
| **Trainset length (m)** | 200.190 | 237.590 |
| **Number of trailers** | 8 | 10 |
| **Width of trailers (m)** | 2.814 | 2.904 |
| **Weight with normal load (t)** | 418 | 490 |
| **Seating**<br>**1st Class**<br>**2nd Class**<br>**Total** | <br>111<br>275<br>386 | <br>116<br>369<br>485 |
| **Continuous rating (kW)**<br>**with 25 kV supply**<br>**with 1.5 kV supply** | <br>6 450<br>3 100 | <br>8 800<br>2 880 |
| **Maximum commercial speed (km/h)** | 270 | 300 |

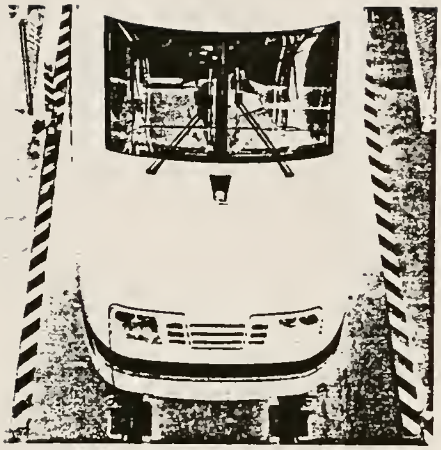
## The "Atlantique" traction motor compared with the "Sud-Est" traction motor

| | **Paris-Sud-Est** | **Atlantique** |
|---|---|---|
| **Type** | DC | AC synchronous |
| **Motors per rake** | 12 | 8 |
| **Weight, bare motor (kg)** | 1 525 | 1 460 |
| **Max. rpm** | 3 000 | 4 000 |
| **Max. power output (kW)** | 580 | 1 100 |

# APPENDIX G

# TECHNICAL DATA RELATED TO THE ICE HIGH-SPEED RAIL SYSTEM OBTAINED FROM THE GERMAN NATIONAL RAILWAYS (DB)

# InterCityExpress
# Technical Specifications



| | |
|---|---|
| Gauge | 1,435 mm |
| Power system | 15 kV, 16-2/3 Hz |
| Maximum service speed | 280 km/h |

**Power unit:**

| | |
|---|---|
| Axle arrangement | Bo'Bo' |
| Service weight | 80 t |
| Continuous rating | 4,800 kW |
| Starting tractive effort | 200 kN |
| Length at coupling level | 20,560 mm |
| Maximum width | 3,070 mm |
| Height of roof above top of rail | 3,840 mm |
| Vehicle gauge | UIC 505 |
| Brake system | Regenerative brakes, electro-pneumatically actuated disc brakes |
| Parking brake | Spring accumulator brakes |
| Max. regenerative brake rating | 4,000 kW |

**Centre coaches:**

| | |
|---|---|
| Axle arrangement | 2'2' |
| Empty weight | |
| ● First and second class coach | Approx. 52 t, 0.8 t water |
| ● Second class coach with special compartments | Approx. 51 t, 0.8 t of water |
| ● Restaurant car | Approx. 55 t, 1 t water, 1.7 t supplies |
| Length overall at coupling level | 26,400 mm |
| Maximum width (at height of 1.80 m above top of rail) | 3,020 mm |
| Height of roof above top of rail | 3,840 mm |
| Number of seats | |
| ● First class coach | 48 |
| ● Second class coach | 66, with special compartments 39 + 4 + 2 |
| ● Restaurant car | 24 in restaurant, 16 in bistro |

### Key data and dimensions of the InterCityExpress.

| | | |
|---|---|---|
| DB type series | Drive unit | 401 |
| | Carriages | 801-804 |
| Track gauge | | 1435 mm |
| Power system | | 15 kV, 16 2/3 Hz |
| Vehhicle gauge | Drive unit | UIC 505 |
| | Carriages | – |
| Years of delivery | | 1989–1992 |
| Design speed | | 280 km/h |
| Train length (with 14 carriages) | | 410.70 m |
| Number of carriages | | Min. 9, max. 14 |
| Seating capacity with 14 carriages | 1st class | 192 |
| | 2nd class | 567 |
| Additional seating in conference section and dining car | | |
| Smallest negotiable radius (coupled) | | 150 m |
| Drawgear and buffing gear | | Semi-automatic central buffercoupling<br>Towing coupling at both ends of the train |
| Safety equipment | | Continuous automatic train control system (LZB80)<br>Inductive train protection (Indusi I 80)<br>Dead man's handle (Sifa)<br>Electric emergency brake loop |
| Brakes | | Electric mains brakes (drive unit)<br>Electropneumatically operated disk brakes (drive unit + carriages)<br>Electromagnetic rail brakes (carriages) |
| Brake type | | KE-R-Mg D-ep |
| Parking brakes | | Spring-loaded brake (drive unit)<br>Spindle brake |

**Drive unit:**

| | |
|---|---|
| Tare weight | Approx. 80,400 kg<br>with GTO thyristors approx. 78,000 kg |
| Length at coupling level | 20,560 mm |
| Drive unit body width | 3,070 mm |
| Roof crown height over top of rail (TOR) | 3,840 mm |
| Pivot distance between running gears | 11,460 mm |
| Axle base in running gear | 3,000 mm |

| | |
|---|---|
| Constant power per drive unit | |
| - Engines (UIC nominal rating) | 4,800 kW |
| - Transformers | Overall rating 5,200 kVA |
| | of which for traction purposes: 4,500 kVA |
| | of which for heating, air-conditioning and auxiliary functions: 700 kVA |
| Power converters | 7,600 kVA |
| Maximum starting tractive power per drive unit | 200 kN |

**Carriages:**

| | | |
|---|---|---|
| Body length at coupling level | | 26,400 mm |
| Maximum width (at 1.80 m height over TOR) | | 3,020 mm |
| Floor height over TOR | | 1,210 mm |
| Roof crown height over TOR | | 3,840 mm |
| Wheel diameter at running level | - new | 920 mm |
| | - worn | 870 mm |
| Axle arrangement | | 2'2' |

**Seating capacity:**

| | |
|---|---|
| 1st class carriages | 48 |
| 2nd class carriages | 66 |
| 2nd class carriages with special compartments | 39 |
| conference section | 4 |
| parking area for wheelchairs | 2 |
| Dining car: restaurant | 24 |
| bistro, max. | 16 |

**Unloaden weight (without passengers but with equipment):**

| | |
|---|---|
| – 1st and 2nd class carriages | approx. 52 t + 0.8 t water = approx. 52.8 t |
| – 2nd class carriages with special compartments | 52.6 t + 1 t water and stocks = 53.6 t |
| – dining car | 55.5 t + 1 t water + 1.7 t stocks = 58.2 t |

**Driving performance:**

| | |
|---|---|
| Acceleration with 14 carriages | |
| from 0 to 100 km/h | 1 minute 6 seconds |
| from 0 to 200 km/h | 3 minutes 20 seconds |
| from 0 to 250 km/h | 6 minutes 20 seconds |

| | |
|---|---|
| Starting distance with 14 carriages | |
| from 0 to 100 km/h | 900 m |
| from 0 to 200 km/h | 6,850 m |
| from 0 to 250 km/h | 18,350 m |

| | |
|---|---|
| Stopping distance from 250 km/h | |
| LZB controlled service breaking ($b = 0.5\ m/s^2$) | 4,820 m |
| Rapid stop ($b + 1.05\ m/s^2$) | 2,300 m |

# APPENDIX H

# TECHNICAL DATA RELATED TO THE X-2000 HIGH-SPEED RAIL SYSTEM OBTAINED FROM A U.S. REPRESENTATIVE OF THE SWEDISH ABB TRACTION COMPANY

ABB
ASEA BROWN BOVERI

April 12, 1993

Mr. Fadi Nassar
University of Florida
345 Weil Hall
Gainsville, FL 32611

Dear Mr. Nassar:

Enclosed, please find a summary of performance data prepared for x2000. The data was assembled to permit the simulation of operating scenarios for the train.

I trust the material will be helpful.

Sincerely,

Joseph S. Silien
Director, Business Development

JSS:mmk

encl.

ABB TRACTION INC.

425 Phillips Boulevard
Trenton, NJ 08618

Telephone:
(609) 538-7900

Telefax:
(609) 538-7993

# X2000 HIGH SPEED TILTING TRAIN

## PERFORMANCE DATA

ABB TRACTION INC.
1992

## List of Figures and Tables

Figure 1. Speed vs Distance
(one power car with 5 cars)

Figure 2. Speed vs Time
(one power car with 5 cars)

Figure 3. Acceleration vs Speed
(one power car with 5 cars)

Figure 4. Deceleration vs Speed
(one power car with 5 cars)

Figure 5. Speed vs Distance
(one power car with 6 cars)

Figure 6. Speed vs Time
(one power car with 6 cars)

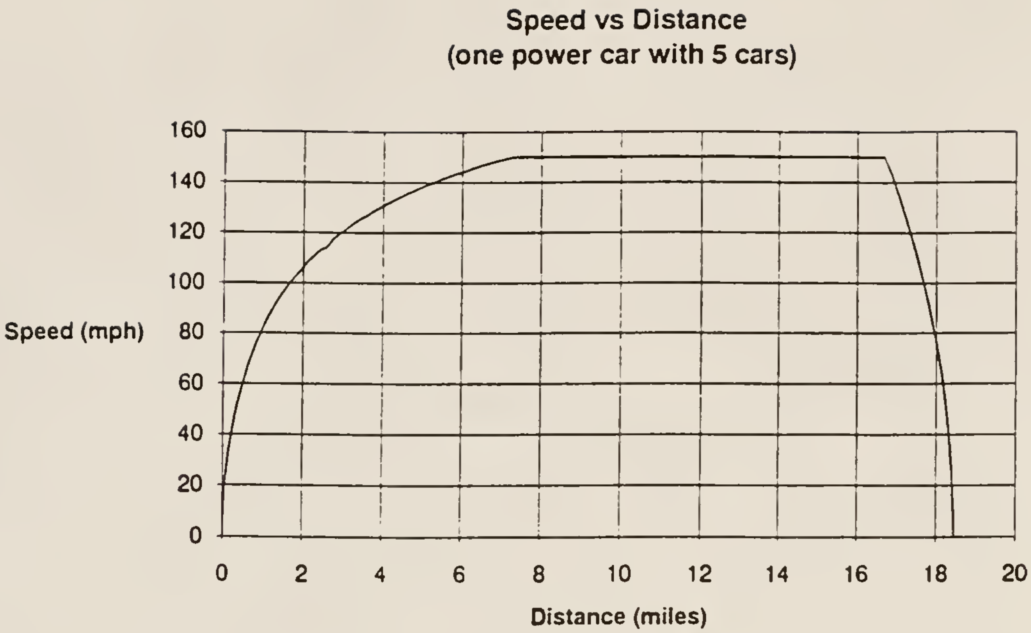
Figure 7. Acceleration vs Speed
(one power car with 6 cars)

Figure 8. Deceleration vs Speed
(one power car with 6 cars)

Figure 9. Tractive Effort vs Speed

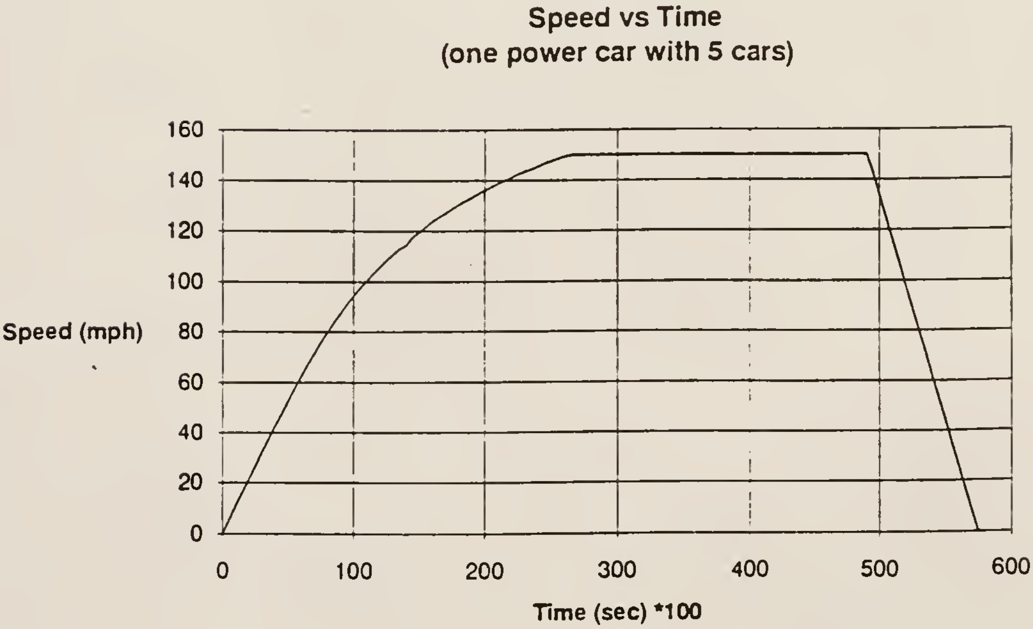
Figure 10. Electric Braking Effort vs Speed

Table 1. Maximum Allowable Operating Speeds for Curved Track



Speed vs Distance
(one power car with 5 cars)

Figure 1.



Speed vs Time
(one power car with 5 cars)

Figure 2.

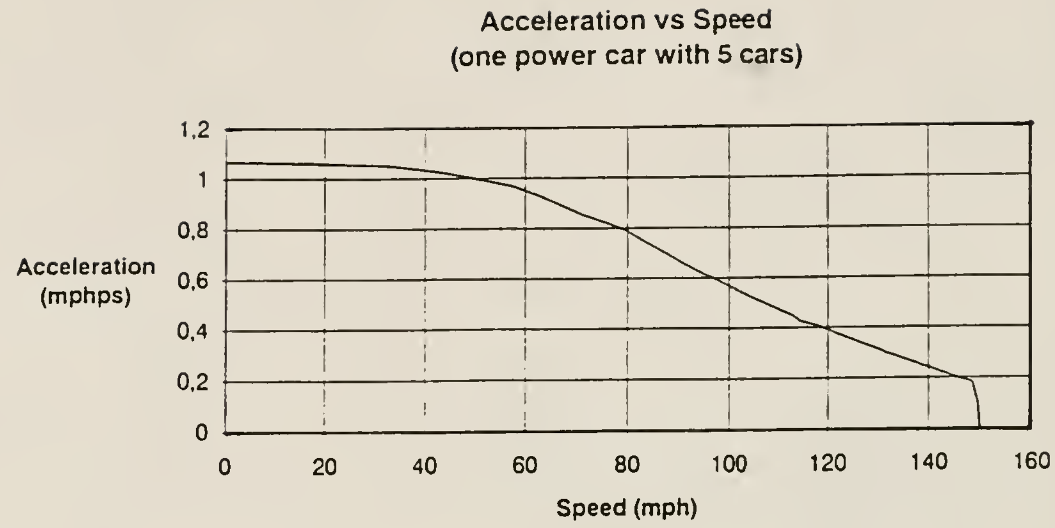


Figure 3.

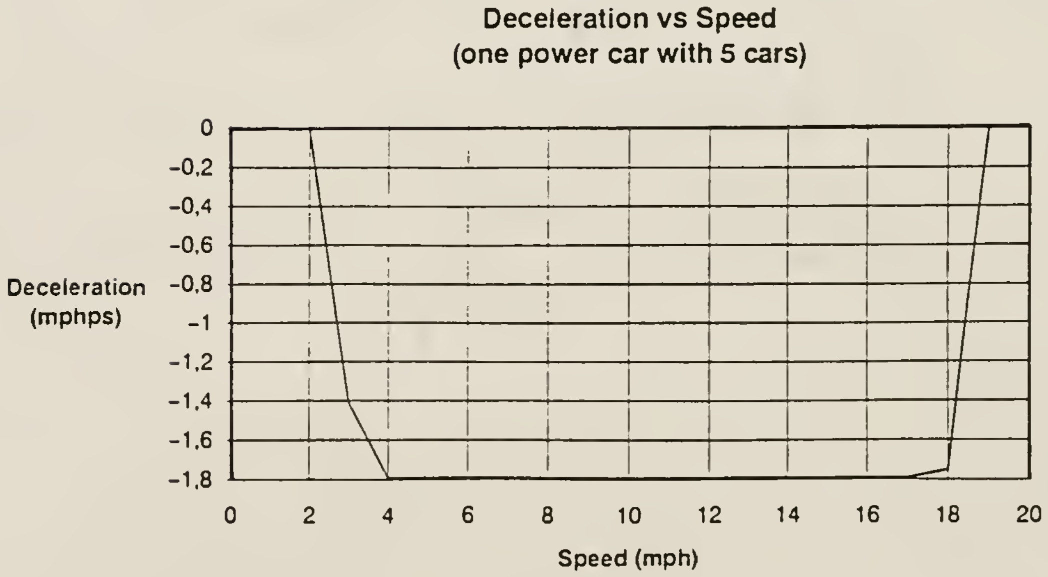


Figure 4.

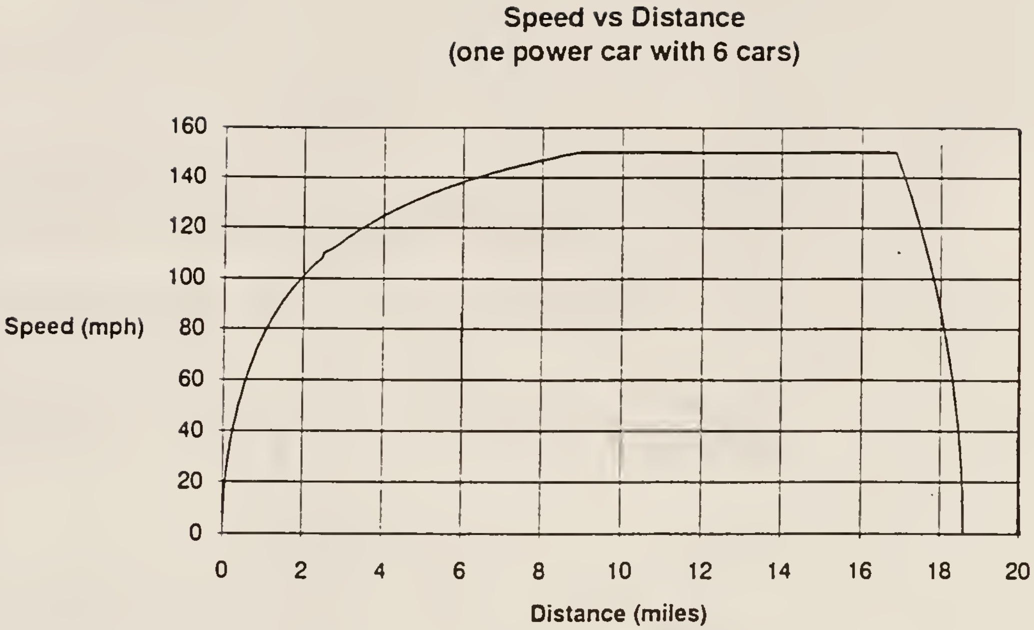

Speed vs Distance
(one power car with 6 cars)

Figure 5.

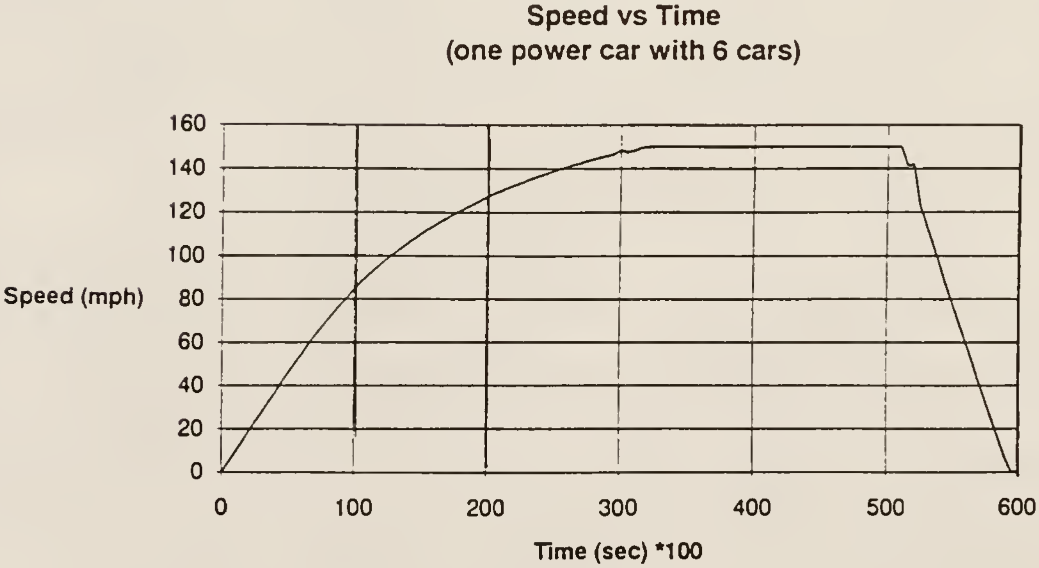

Speed vs Time
(one power car with 6 cars)

Figure 6.

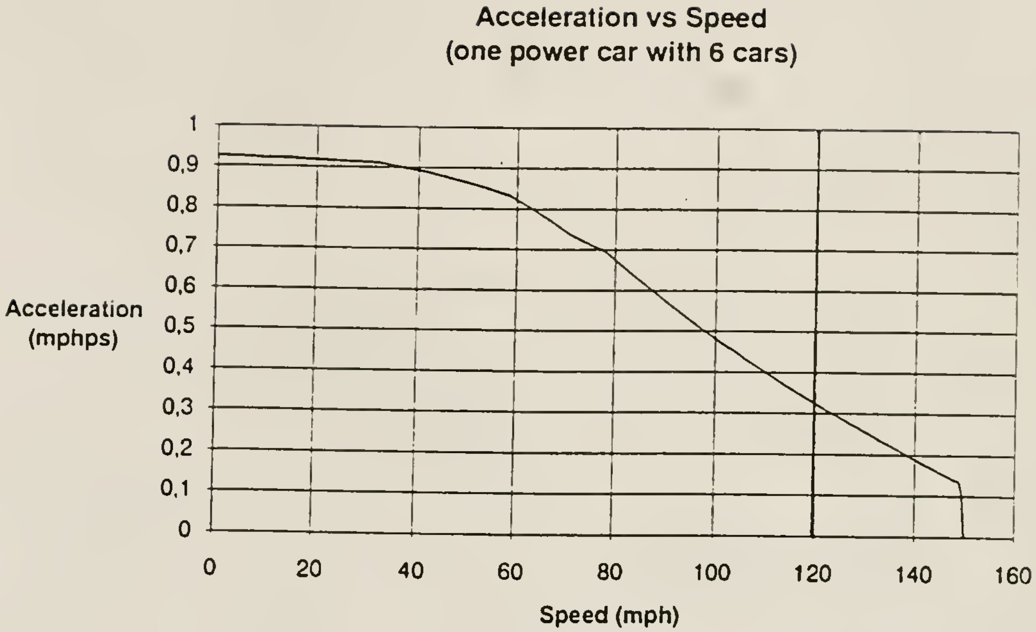


Figure 7.

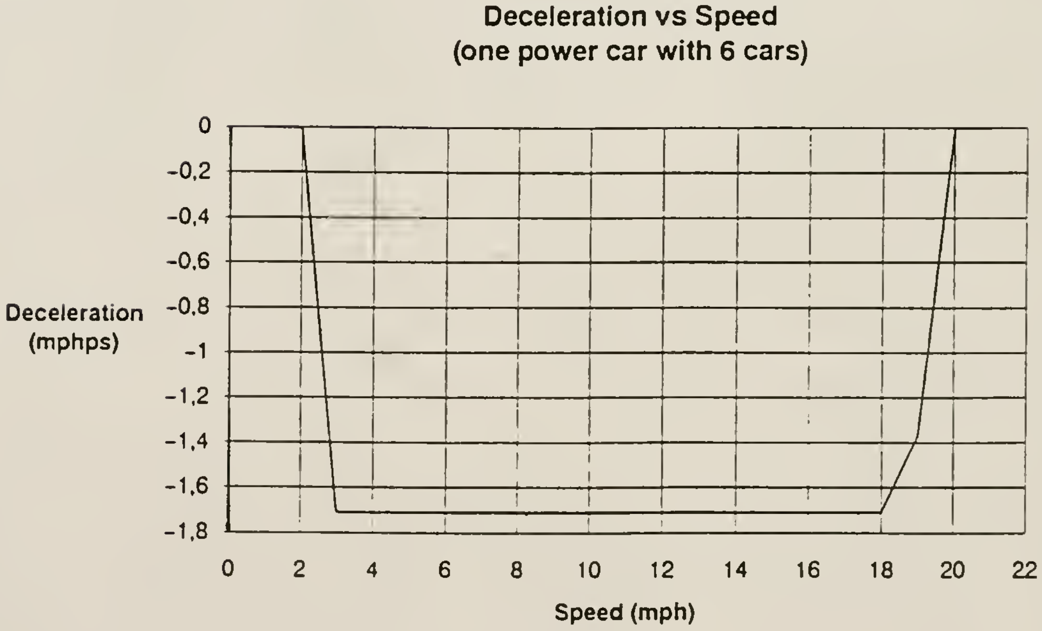


Figure 8.

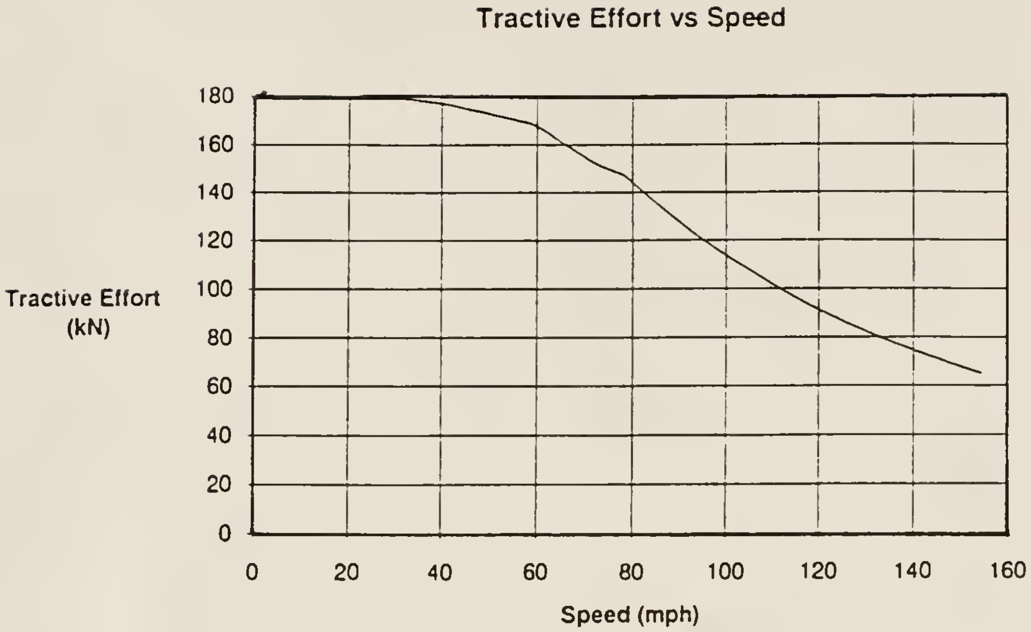


Figure 9.

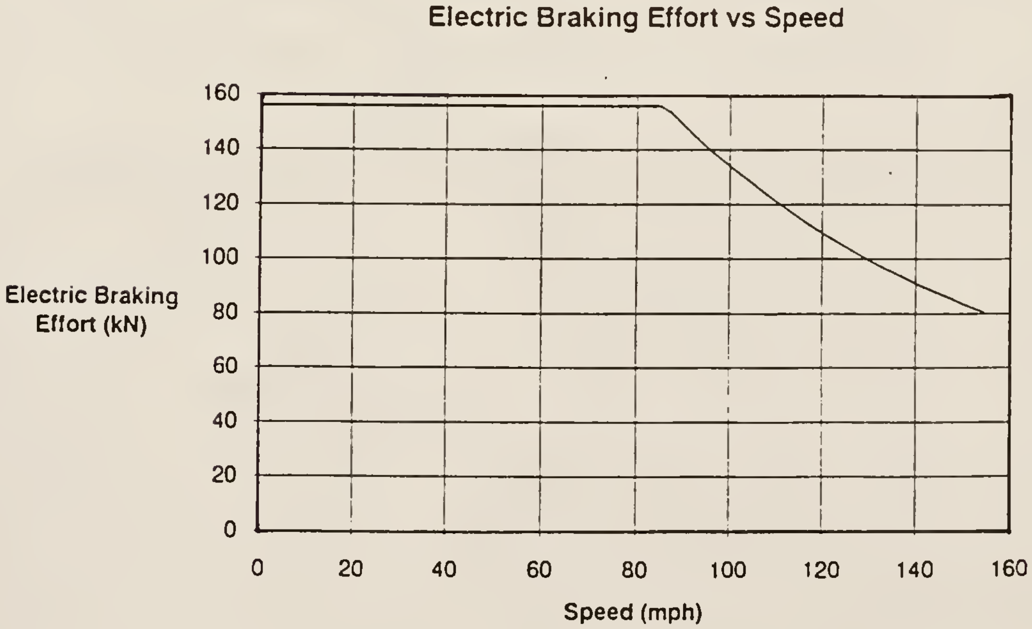


Figure 10.

Table 1. Maximum Allowable Operating Speeds For Curved Track (mph)

$$V_{max} = \sqrt{\frac{E + Cd_{X2000}}{0.0007 \cdot D}}$$

where $Cd_{X2000}$ = 9.685 inches
$E$ = Elevation of outer rail (inches)
$D$ = Degree of Curvature (degrees)

| Degree of Curvature | Elevation of outer rail (inches) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 0,5 | 1 | 1,5 | 2 | 2,5 | 3 | 3,5 | 4 | 4,5 | 5 | 5,5 | 6 |
| 0°40' | 144 | 147 | | | | | | | | | | | |
| 0°50' | 129 | 132 | 136 | 139 | 142 | 145 | 148 | | | | | | |
| 1°00' | 118 | 121 | 124 | 126 | 129 | 132 | 135 | 137 | 140 | 142 | 145 | 147 | 150 |
| 1°15' | 105 | 108 | 111 | 113 | 116 | 118 | 120 | 123 | 125 | 127 | 130 | 132 | 134 |
| 1°30' | 96 | 98 | 101 | 103 | 105 | 108 | 110 | 112 | 114 | 116 | 118 | 120 | 122 |
| 1°45' | 89 | 91 | 93 | 96 | 98 | 100 | 102 | 104 | 106 | 108 | 109 | 111 | 113 |
| 2°00' | 83 | 85 | 87 | 89 | 91 | 93 | 95 | 97 | 99 | 101 | 102 | 104 | 106 |
| 2°15' | 78 | 80 | 82 | 84 | 86 | 88 | 90 | 91 | 93 | 95 | 97 | 98 | 100 |
| 2°30' | 74 | 76 | 78 | 80 | 82 | 83 | 85 | 87 | 88 | 90 | 92 | 93 | 95 |
| 2°45' | 71 | 73 | 75 | 76 | 78 | 80 | 81 | 83 | 84 | 86 | 87 | 89 | 90 |
| 3°00' | 68 | 70 | 71 | 73 | 75 | 76 | 78 | 79 | 81 | 82 | 84 | 85 | 86 |
| 3°15' | 65 | 67 | 69 | 70 | 72 | 73 | 75 | 76 | 78 | 79 | 80 | 82 | 83 |
| 3°30' | 63 | 64 | 66 | 68 | 69 | 71 | 72 | 73 | 75 | 76 | 77 | 79 | 80 |
| 3°45' | 61 | 62 | 64 | 65 | 67 | 68 | 70 | 71 | 72 | 74 | 75 | 76 | 77 |
| 4°00' | 59 | 60 | 62 | 63 | 65 | 66 | 67 | 69 | 70 | 71 | 72 | 74 | 75 |
| 4°30' | 55 | 57 | 58 | 60 | 61 | 62 | 63 | 65 | 66 | 67 | 68 | 69 | 71 |
| 5°00' | 53 | 54 | 55 | 57 | 58 | 59 | 60 | 61 | 63 | 64 | 65 | 66 | 67 |
| 5°30' | 50 | 51 | 53 | 54 | 55 | 56 | 57 | 59 | 60 | 61 | 62 | 63 | 64 |
| 6°00' | 48 | 49 | 50 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 |
| 6°30' | 46 | 47 | 48 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 |
| 7°00' | 44 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 |
| 8°00' | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 49 | 50 | 51 | 52 | 53 |
| 9°00' | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 47 | 48 | 49 | 50 |
| 10°00' | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 43 | 44 | 45 | 46 | 47 | 47 |
| 11°00' | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 41 | 42 | 43 | 44 | 44 | 45 |
| 12°00' | 34 | 35 | 36 | 36 | 37 | 38 | 39 | 40 | 40 | 41 | 42 | 43 | 43 |

### CARBODY TILTING SYSTEM

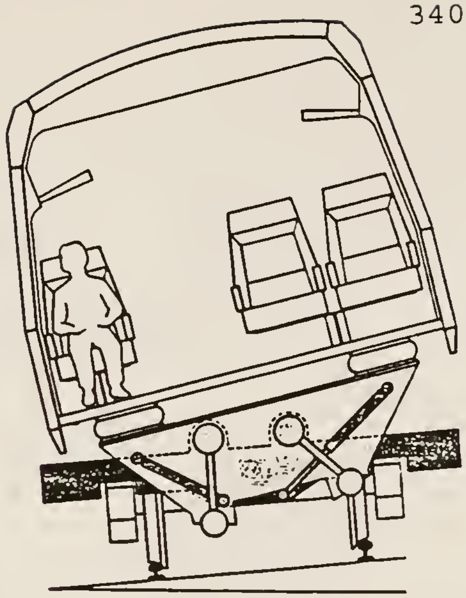
Active tilting system of all passanger cars
Separate hydraulic system on each car

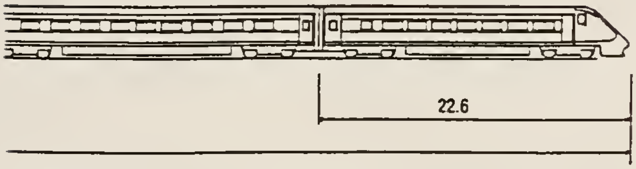
| | |
|---|---|
| Maximum tilting angle | 8° |
| Maximum tilting speed | 4° /second |
| Compensation factor | 70% |

### SYSTEM FÜR WAGENKASTENNEIGUNG

Aktives Wagenkastenneigungssystem für alle Mittelwagen.
Getrenntes hydraulisches System für jeden Wagen.

| | |
|---|---|
| Maximaler Neigungswinkel | 8° |
| Maximale Neigungsgeschwindigkeit | 4°/s |
| Kompensationsfaktor | 70% |





### CARBODIES

Stainless steel 18% Cr, 8% Ni
UIC 566 strength requirements
Loads above sidesill, UIC 566, requirements +50%

### COUPLERS

Automatic couplers at train ends
Semipermanent couplers between cars

### DOORS

Automatic sliding-plug exterior doors
Automatic sliding interior doors

### AIR CONDITIONING AND VENTILATION

Air volume per intermediate passanger car 3200 $m^3$
Maximum 50% recirculation
Compressor condensor unit in underframe
Evaporator, ventilation fans overhead mounted

### WAGENKASTEN

Rostfreier Stahl 18% Cr, 8% Ni
Festigkeit nach UIC 566
Last über Längsträger nach UIC 566 + 50%

### KUPPLUNGEN

Automatische Kupplungen an den Zugenden
Halbdauerkupplungen zwischen den Wagen

### TÜREN

Automatische Schiebe-Falt-Türen aussen
Automatische Schiebetüren innen

### KLIMATISIERUNG UND BELÜFTUNG

Luftmenge pro Wagen 3200 $m^3$
Luftumwälzung maximal 50%
Verdichter-Kondensator-Aggregat im Rahmen
Verdampfer, Lüfter oben im Wagen

### CONTROL SYSTEM

ABB Tracs system
2-wire data bus
Fault indication/diagnosis system integrated in control system

### BRAKE SYSTEM

| | |
|---|---|
| Retardation, service brake | 1.1 $m/s^2$ |
| Retardation, emergency brake | 1.4 $m/s^2$ |

Electropneumatic brake system with all-pneumatic backup
Regenerative electric brake, prioritised
Disc and thread brake on power car bogies
Disc and magnetic track brake on passanger car bogies
Screw air compressor

### BOGIES

| | |
|---|---|
| Axle distance, power car and passanger car bogie | 2,9 m |
| Wheel diameter, power car bogie (new/worn) | 1100/1040 mm |
| Wheel diameter, passanger car bogies (new/worn) | 880/820 mm |

### LEITSYSTEM

ABB-Tracs-System
2-Leiter-Datenbus
Störungsanzeige- und Diagnosesystem ist in das Leitsystem integriert

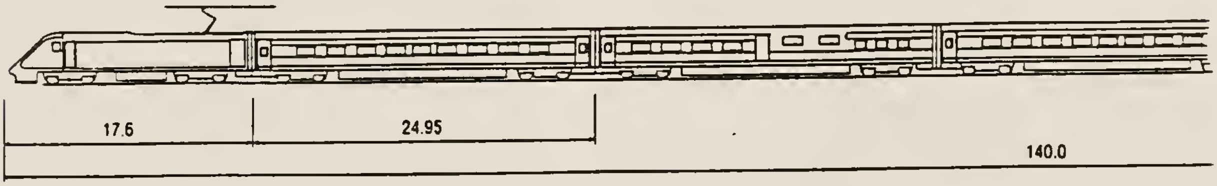
### BREMSSYSTEM

| | |
|---|---|
| Verzögerung, Betriebsbremse | 1,1 $m/s^2$ |
| Verzögerung, Notbremse | 1,4 $m/s^2$ |

Elektropneumatische Bremsanlage mit pneumatischer Reserve
Elektrische Nutzbremse, wird vorrangig benutzt
Scheiben- und Klotzbremse an den Drehgestellen des Triebkopfes
Scheiben- und Magnetschienenbremse an den Drehgestellen der Mittelwagen
Schraubenverdichter

### DREHGESTELLE

| | |
|---|---|
| Achsabstand Drehgestell Triebkopf und Mittelwagen | 2,9 m |
| Raddurchmesser, Drehgestell Triebkopf (neu/abgefahren) | 1100/1040 mm |
| Raddurchmesser, Drehgestelle Mittelwagen (neu/abgefahren) | 880/820 mm |



# APPENDIX I

# MAGLEV MODULE OF THE COST MODEL WRITTEN IN DBASE IV

```
*       ************************************************
*                MAGLEV MODULE OF THE COST MODEL
*                     WRITTEN IN DBASE IV
*            ******************************************


*--- MAGMENU MODULE --
CLEAR
*
SET TALK OFF
SET STATUS OFF
SET BELL OFF
SET SCOREBOARD OFF
*
CD1FILE="        "
UC1FILE="        "
PUBLIC LONG, SECT, ICODE, LKCODE
LONG = 0
SECT = 0
ICODE = "1K        "
*
@8,5 TO 18,70 DOUBLE COLOR R/B
@10,10 SAY "Enter Name of Code-File:"
@10,52 GET CD1FILE
@12,10 SAY "Enter Unit Cost Database:"
@12,52 GET UC1FILE
@14,10 SAY "Enter Route Length (km):"
@14,54 GET LONG PICTURE "999.99"
@16,10 SAY "Enter Length of each Route Section (km):"
@16,56 GET SECT PICTURE "9.99"
READ
*
TSECT = INT(LONG/SECT)
CDFILE = TRIM(CD1FILE)+".DBF"
UCFILE = TRIM(UC1FILE)+".DBF"
*
CLEAR
*
IF LONG>0 .AND. SECT>0
   *USE TEMPLATE
   USE TEMPL2
   COPY NEXT TSECT TO &CDFILE
   CLOSE DATABASES
   *
   CLEAR
   *
   USE &CDFILE
   REPLACE ALL KM WITH SECTION*SECT
ELSE
   USE &CDFILE
   GO TOP
   STORE KM TO SECT
   GO BOTTOM
   STORE KM TO LONG
ENDIF

CLOSE DATABASES
*
*PROCEDURE A1
     SET COLOR OF BOX TO R/B
     SET BORDER TO SINGLE
     SET COLOR TO W/B, N/G, R
     *@ 1,12 TO 23,79 DOUBLE COLOR R/B
     *@ 0,0 TO 23,11 DOUBLE COLOR R/B
     @ 1,17 TO 23,79 DOUBLE COLOR R/B
     @ 0,0 TO 23,16 DOUBLE COLOR R/B
     @ 3,1 TO 3,15 DOUBLE COLOR R/B
     @ 5,1 TO 5,15 COLOR R/B
     @ 7,1 TO 7,15 COLOR R/B
     @ 9,1 TO 9,15 COLOR R/B
     @ 11,1 TO 11,15 COLOR R/B
     @ 13,1 TO 13,15 COLOR R/B
     @ 15,1 TO 15,15 COLOR R/B
     @ 17,1 TO 17,15 COLOR R/B
     @ 19,1 TO 19,15 COLOR R/B
     @ 21,1 TO 21,15 COLOR R/B
     @ 1,1 SAY "   MAGLEV" COLOR G+/B
     @ 2,1 SAY "CAPITAL ITEMS" COLOR G+/B
     @ 1,35 SAY "  CODE-GENERATOR MENU  " COLOR G+/B
     @ 0,34 TO 2,58 DOUBLE COLOR R/B
*RETURN

*--- DEFINE VERTICAL BAR MENU
DEFINE MENU MAINMENU MESSAGE "SELECT ITEM"

*--- DEFINE OPTIONS
DEFINE PAD GUIDEWAY OF MAINMENU AT 4,1 PROMPT "GUIDEWAY/ROW";
     MESSAGE "SELECT GUIDEWAY TYPES FOR ALL ROUTE SECTIONS"
DEFINE PAD POWER OF MAINMENU AT 6,1 PROMPT "POWER SUPPLY";
     MESSAGE "SELECT ELECTRIFICATION COMPONENTS"
DEFINE PAD SIGNAL OF MAINMENU AT 8,1 PROMPT "SIGNALS & COMM.";
     MESSAGE "SELECT SIGNALS AND COMMUNICATION EQUIPMENTS"
DEFINE PAD EARTHWORK OF MAINMENU AT 10,1 PROMPT "EARTHWORKS";
     MESSAGE "SELECT EXCAVATION/BACKFILL/DISPOSAL OPERATIONS"
DEFINE PAD OVERPASS OF MAINMENU AT 12,1 PROMPT "OVERPASSES";
     MESSAGE "SELECT MAGLEV AND HIGHWAY OVERPASSES"
DEFINE PAD FACILITY OF MAINMENU AT 14,1 PROMPT "STATIONS/O&M";
     MESSAGE "SELECT O&M FACILITIES AND STATIONS"
DEFINE PAD STRUCTURE OF MAINMENU AT 16,1 PROMPT "SPEC.
STRUCTURE";
     MESSAGE "SELECT TUNNEL/LONG BRIDGE/CUT & COVER/NOISE WALL"
DEFINE PAD TRAIN OF MAINMENU AT 18,1 PROMPT "TRAINSETS";
     MESSAGE "SELECT MAGLEV TRAINSETS"
```

```
DEFINE PAD ADJUST OF MAINMENU AT 20,1 PROMPT "ADJUSTMENTS";
     MESSAGE "ADJUSTMENT FOR LOCATION/TOPOGRAPHY/JOB CONDITION"
DEFINE PAD QUIT OF MAINMENU AT 22,1 PROMPT "QUIT";
     MESSAGE "EXIT THIS MENU"

*--- DEFINE ACTION FOR EACH PAD
ON SELECTION PAD GUIDEWAY OF MAINMENU ACTIVATE POPUP P1GUID
ON SELECTION PAD POWER OF MAINMENU DO POWER1
ON SELECTION PAD SIGNAL OF MAINMENU DO SIGNAL1
ON SELECTION PAD EARTHWORK OF MAINMENU DO EARTH1
ON SELECTION PAD OVERPASS OF MAINMENU DO OVERPASS1
ON SELECTION PAD FACILITY OF MAINMENU DO FACILITY1
ON SELECTION PAD STRUCTURE OF MAINMENU DO STRUCT1
ON SELECTION PAD TRAIN OF MAINMENU DO TRAINSET1
ON SELECTION PAD ADJUST OF MAINMENU DO ADJUST1
ON SELECTION PAD QUIT OF MAINMENU DO FIN

*--- DEFINE GUIDEWAY POPUP
SET BORDER TO DOUBLE
DEFINE POPUP P1GUID FROM 5,19
SET COLOR OF BOX TO R/B
DEFINE BAR 1 OF P1GUID PROMPT "     * LEVEL 1 *" SKIP
DEFINE BAR 2 OF P1GUID PROMPT REPLICATE (CHR(205),21) SKIP
DEFINE BAR 3 OF P1GUID PROMPT "Single Track Guideway";
     MESSAGE "SELECT SINGLE TRACK GUIDEWAY"
DEFINE BAR 4 OF P1GUID PROMPT "Double Track Guideway";
     MESSAGE "SELECT DOUBLE TRACK GUIDEWAY"
DEFINE BAR 5 OF P1GUID PROMPT "Guideway Switch";
        MESSAGE "SELECT GUIDEWAY SWITCH"
DEFINE BAR 6 OF P1GUID PROMPT "Right-of-Way";
        MESSAGE "SELECT RIGHT-OF-WAY FOR GUIDEWAY"
DEFINE BAR 7 OF P1GUID PROMPT REPLICATE (CHR(196),21) SKIP
DEFINE BAR 8 OF P1GUID PROMPT "View/Edit Unit Costs";
     MESSAGE "VIEW/EDIT UNIT COST DATABASE"
DEFINE BAR 9 OF P1GUID PROMPT "View/Edit Code File";
     MESSAGE "VIEW/EDIT CODE FILE"
DEFINE BAR 10 OF P1GUID PROMPT "Enter Guideway Data";
     MESSAGE "ENTER GUIDEWAY DATA IN CODE FILE"
DEFINE BAR 11 OF P1GUID PROMPT "EXIT";
     MESSAGE "EXIT THIS MENU"
*
ON SELECTION POPUP P1GUID BLANK DO P1GUID2
*
ACTIVATE MENU MAINMENU
RELEASE MENU MAINMENU
SET COLOR TO W/B
SET TALK ON
*CLEAR
*
PROCEDURE P1GUID2
   DO CASE
      CASE BAR()=3
```

```
         LKCODE="1KGS*"
         DO WIN_CODE
         DO SINGLE
     CASE BAR()=4
         LKCODE="1KGD*"
         DO WIN_CODE
         DO DOUBLE
     CASE BAR()=5
         LKCODE="1KGX*"
         DO WIN_CODE
         ICODE="1KGX          "
         CFIELD="SWITCHES"
         SA="Switches"
         DO WIN_DATA2
     CASE BAR()=6
         LKCODE="XXX"
         DO WIN_CODE
         ICODE="X-            "
         CFIELD="ROW"
         SA="Right-of-way"
         DO WIN_DATA
     CASE BAR()=8
         DO COSTEDIT
     CASE BAR()=9
         DO CODEEDIT
     CASE BAR()=10
         ICODE="1KG           "
         CFIELD="GUIDEWAY"
            SA="Guideway"
            DO WIN_DATA
     CASE BAR()=11
         DEACTIVATE POPUP
   ENDCASE
RETURN
*
*
PROCEDURE SINGLE
     DEFINE POPUP SINGLE FROM 5,30
     DEFINE BAR 1 OF SINGLE PROMPT "   * LEVEL 2-A *" SKIP
     DEFINE BAR 2 OF SINGLE PROMPT REPLICATE (CHR(205),20) SKIP
     DEFINE BAR 3 OF SINGLE PROMPT "Single Elevated";
          MESSAGE "SELECT SINGLE ELEVATED GUIDEWAY"
     DEFINE BAR 4 OF SINGLE PROMPT "Single Near-Grade";
          MESSAGE "SELECT SINGLE NEAR-GRADE GUIDEWAY"
     DEFINE BAR 5 OF SINGLE PROMPT REPLICATE (CHR(196),20) SKIP
     DEFINE BAR 6 OF SINGLE PROMPT "View/Edit Unit Costs";
          MESSAGE "VIEW/EDIT UNIT COST DATABASE"
     DEFINE BAR 7 OF SINGLE PROMPT "Enter Guideway Data";
          MESSAGE "ENTER GUIDEWAY DATA IN CODE FILE"
     DEFINE BAR 8 OF SINGLE PROMPT "EXIT";
          MESSAGE "EXIT THIS MENU"
        ON SELECTION POPUP SINGLE BLANK DO SINGLE2
        ACTIVATE POPUP SINGLE
RETURN
*
PROCEDURE SINGLE2
   DO CASE
     CASE BAR()=3
         LKCODE="1KGSE*"
         DO WIN_CODE
         ICODE ="1KGSE        "
         CFIELD="GUIDEWAY"
         SA="Guideway"
         DO WIN_DATA
     CASE BAR()=4
         LKCODE="1KGSN*"
         DO WIN_CODE
         ICODE ="1KGSN        "
         CFIELD="GUIDEWAY"
         SA="Guideway"
         DO WIN_DATA
     CASE BAR()=6
         DO COSTEDIT
     CASE BAR()=7
         ICODE ="1KGS         "
            CFIELD="GUIDEWAY"
            SA="Guideway"
            DO WIN_DATA
     CASE BAR()=8
         DEACTIVATE POPUP
   ENDCASE
RETURN
*
PROCEDURE DOUBLE
     DEFINE POPUP DOUBLE FROM 8,30
     DEFINE BAR 1 OF DOUBLE PROMPT "   * LEVEL 2-B *" SKIP
     DEFINE BAR 2 OF DOUBLE PROMPT REPLICATE (CHR(205),20) SKIP
     DEFINE BAR 3 OF DOUBLE PROMPT "Double Elevated";
          MESSAGE "SELECT DOUBLE ELEVATED GUIDEWAY"
     DEFINE BAR 4 OF DOUBLE PROMPT "Double Near-Grade";
          MESSAGE "SELECT DOUBLE NEAR-GRADE GUIDEWAY"
     DEFINE BAR 5 OF DOUBLE PROMPT REPLICATE (CHR(196),20) SKIP
     DEFINE BAR 6 OF DOUBLE PROMPT "View/Edit Unit Costs";
          MESSAGE "VIEW/EDIT UNIT COST DATABASE"
     DEFINE BAR 7 OF DOUBLE PROMPT "Enter Guideway Data";
          MESSAGE "STORE GUIDEWAY DATA IN CODE FILE "
     DEFINE BAR 8 OF DOUBLE PROMPT "EXIT";
          MESSAGE "EXIT THIS MENU"
        ON SELECTION POPUP DOUBLE BLANK DO DOUBLE2
        ACTIVATE POPUP DOUBLE
RETURN
*
PROCEDURE DOUBLE2
   DO CASE
```

```
     CASE BAR()=3
         LKCODE="1KGDE*"
         DO WIN_CODE
         ICODE ="1KGDE        "
         CFIELD="GUIDEWAY"
         SA="Guideway"
         DO WIN_DATA
     CASE BAR()=4
         LKCODE="1KGDN*"
         DO WIN_CODE
         ICODE ="1KGDN        "
         CFIELD="GUIDEWAY"
         SA="Guideway"
         DO WIN_DATA
     CASE BAR()=6
         DO COSTEDIT
     CASE BAR()=7
         ICODE ="1KGD         "
            CFIELD="GUIDEWAY"
            SA="Guideway"
            DO WIN_DATA
     CASE BAR()=8
         DEACTIVATE POPUP
   ENDCASE
RETURN
*
*
*--- DEFINE POWER POPUP
PROCEDURE POWER1
  SET BORDER TO DOUBLE
  DEFINE POPUP POWER2 FROM 3,21
  SET COLOR OF BOX TO R/B
  DEFINE BAR 1 OF POWER2 PROMPT "     * LEVEL 1 *" SKIP
  DEFINE BAR 2 OF POWER2 PROMPT REPLICATE (CHR(205),21) SKIP
  DEFINE BAR 3 OF POWER2 PROMPT "Power Supply";
     MESSAGE "SELECT MAGLEV POWER SUPPLY"
  DEFINE BAR 4 OF POWER2 PROMPT "Power Substations";
     MESSAGE "SELECT MAGLEV POWER SUBSTATIONS"
  DEFINE BAR 5 OF POWER2 PROMPT "Power Switches";
     MESSAGE "SELECT MAGLEV POWER SWITHCES"
  DEFINE BAR 6 OF POWER2 PROMPT "Power Line Feeders";
     MESSAGE "SELECT MAGLEV POWER LINE FEEDERS"
  DEFINE BAR 7 OF POWER2 PROMPT "Long Stator";
     MESSAGE "SELECT MAGLEV LONG STATOR POWER SYSTEM"
  DEFINE BAR 8 OF POWER2 PROMPT REPLICATE (CHR(196),21) SKIP
  DEFINE BAR 9 OF POWER2 PROMPT "View/Edit Unit Costs";
     MESSAGE "VIEW/EDIT UNIT COST DATABASE"
  DEFINE BAR 10 OF POWER2 PROMPT "View/Edit Code File";
     MESSAGE "VIEW/EDIT CODE FILE"
  DEFINE BAR 11 OF POWER2 PROMPT "EXIT";
     MESSAGE "EXIT THIS MENU"
*
```

```
  ON SELECTION POPUP POWER2 BLANK DO POWER22
  ACTIVATE POPUP POWER2
RETURN
*
*
PROCEDURE POWER22
   DO CASE
     CASE BAR()=3
         LKCODE="1KPP*"
         DO WIN_CODE
         ICODE="1KPP         "
         CFIELD="POWER"
         SA="Power Supply"
         DO WIN_DATA
     CASE BAR()=4
         LKCODE="1KPS*"
         DO WIN_CODE
         ICODE="1KPS         "
         CFIELD="SUBSTATION"
         SA="Substations"
         DO WIN_DATA2
     CASE BAR()=5
         LKCODE="1KPX*"
         DO WIN_CODE
         ICODE="1KPX         "
         CFIELD="P_SWITCH"
         SA="Power Switch"
         DO WIN_DATA
     CASE BAR()=6
         LKCODE="1KPF*"
         DO WIN_CODE
         ICODE="1KPF         "
         CFIELD="P_FEEDER"
         SA="Line Feeders"
         DO WIN_DATA
     CASE BAR()=7
         LKCODE="1KPT*"
         DO WIN_CODE
         ICODE="1KPT         "
         CFIELD="STATOR"
         SA="Stator"
         DO WIN_DATA
     CASE BAR()=9
         DO COSTEDIT
     CASE BAR()=10
         DO CODEEDIT
     CASE BAR()=11
         DEACTIVATE POPUP
   ENDCASE
RETURN

*
```

```
*--- DEFINE SIGNAL POPUP
PROCEDURE SIGNAL1
  SET BORDER TO DOUBLE
  DEFINE POPUP SIGNAL2 FROM 5,19
  SET COLOR OF BOX TO R/B
  DEFINE BAR 1 OF SIGNAL2 PROMPT "     * LEVEL 1 *" SKIP
  DEFINE BAR 2 OF SIGNAL2 PROMPT REPLICATE (CHR(205),21) SKIP
  DEFINE BAR 3 OF SIGNAL2 PROMPT "SIGNAL EQUIPMENTS";
     MESSAGE "SELECT MAGLEV SIGNAL EQUIPMENTS"
  DEFINE BAR 4 OF SIGNAL2 PROMPT "COMMUNICAION EQUIPS.";
     MESSAGE "SELECT MAGLEV COMMUNICATION EQUIPMENTS"
  DEFINE BAR 5 OF SIGNAL2 PROMPT REPLICATE (CHR(196),21) SKIP
  DEFINE BAR 6 OF SIGNAL2 PROMPT "View/Edit Unit Costs";
     MESSAGE "VIEW/EDIT UNIT COST DATABASE"
  DEFINE BAR 7 OF SIGNAL2 PROMPT "View/Edit Code File";
     MESSAGE "VIEW/EDIT CODE FILE"
  DEFINE BAR 8 OF SIGNAL2 PROMPT "EXIT";
     MESSAGE "EXIT THIS MENU"
*
  ON SELECTION POPUP SIGNAL2 BLANK DO SIGNAL22
  ACTIVATE POPUP SIGNAL2
RETURN
*
*
PROCEDURE SIGNAL22
   DO CASE
     CASE BAR()=3
         LKCODE="1KCS*"
         DO WIN_CODE
         ICODE="1KCS     "
         CFIELD="SIGNALS"
         SA="Signal"
         DO WIN_DATA
     CASE BAR()=4
         LKCODE="1KCC*"
         DO WIN_CODE
         ICODE="1KCC     "
         CFIELD="DATA_LINK"
         SA="Communication"
         DO WIN_DATA
     CASE BAR()=6
         DO COSTEDIT
     CASE BAR()=7
         DO CODEEDIT
     CASE BAR()=8
         DEACTIVATE POPUP
   ENDCASE
RETURN
*
*--- DEFINE EARTHWORK POPUP
PROCEDURE EARTH1
  SET BORDER TO DOUBLE
  DEFINE POPUP EARTH2 FROM 5,19
  SET COLOR OF BOX TO R/B
  DEFINE BAR 1 OF EARTH2 PROMPT "     * LEVEL 1 *" SKIP
  DEFINE BAR 2 OF EARTH2 PROMPT REPLICATE (CHR(205),21) SKIP
  DEFINE BAR 3 OF EARTH2 PROMPT "Soil Excavation";
     MESSAGE "SELECT SOIL EXCAVATION ACTIVITIES"
  DEFINE BAR 4 OF EARTH2 PROMPT "Soil Backfill";
     MESSAGE "SELECT SOIL BACKFILL ACTIVITIES"
  DEFINE BAR 5 OF EARTH2 PROMPT "Soil Disposal";
        MESSAGE "SELECT SOIL DISPOSAL ACTIVITIES"
  DEFINE BAR 6 OF EARTH2 PROMPT REPLICATE (CHR(196),21) SKIP
  DEFINE BAR 7 OF EARTH2 PROMPT "View/Edit Unit Costs";
     MESSAGE "VIEW/EDIT UNIT COST DATABASE"
  DEFINE BAR 8 OF EARTH2 PROMPT "View/Edit Code File";
     MESSAGE "VIEW/EDIT CODE FILE"
  DEFINE BAR 9 OF EARTH2 PROMPT "EXIT";
     MESSAGE "EXIT THIS MENU"
*
  ON SELECTION POPUP EARTH2 BLANK DO EARTH22
  ACTIVATE POPUP EARTH2
RETURN
*
*
PROCEDURE EARTH22
   DO CASE
     CASE BAR()=3
         LKCODE="1KEX*"
         DO WIN_CODE
         ICODE="1KEX          "
         CFIELD="EXCAVATION"
         SA="Excavation"
         DO WIN_DATA
     CASE BAR()=4
         LKCODE="1KEB*"
         DO WIN_CODE
         ICODE="1KEB          "
         CFIELD="BACKFILL"
         SA="Backfill"
         DO WIN_DATA
     CASE BAR()=5
         LKCODE="1KED*"
         DO WIN_CODE
         ICODE="1KED           "
         SA="Disposal"
         CFIELD="DISPOSAL"
         DO WIN_DATA
     CASE BAR()=7
         DO COSTEDIT
     CASE BAR()=8
         DO CODEEDIT
     CASE BAR()=9
         DEACTIVATE POPUP
   ENDCASE
RETURN


*--- DEFINE OVERPASS1 POPUP
PROCEDURE OVERPASS1
  SET BORDER TO DOUBLE
  DEFINE POPUP OVERPASS2 FROM 7,21
  SET COLOR OF BOX TO R/B
  DEFINE BAR 1 OF OVERPASS2 PROMPT "     * LEVEL 1 *" SKIP
  DEFINE BAR 2 OF OVERPASS2 PROMPT REPLICATE (CHR(205),21) SKIP
  DEFINE BAR 3 OF OVERPASS2 PROMPT "Highway Overpass";
     MESSAGE "SELECT HIGHWAY OVERPASS"
  DEFINE BAR 4 OF OVERPASS2 PROMPT "Maglev Overpass";
     MESSAGE "SELECT MAGLEV OVERPASS"
  DEFINE BAR 5 OF OVERPASS2 PROMPT "Special Overpass";
        MESSAGE "SELECT SPECIAL OVERPASS"
 DEFINE BAR 6 OF OVERPASS2 PROMPT REPLICATE (CHR(196),21) SKIP
  DEFINE BAR 7 OF OVERPASS2 PROMPT "View/Edit Unit Costs";
     MESSAGE "VIEW/EDIT UNIT COST DATABASE"
  DEFINE BAR 8 OF OVERPASS2 PROMPT "View/Edit Code File";
     MESSAGE "VIEW/EDIT CODE FILE"
  DEFINE BAR 9 OF OVERPASS2 PROMPT "EXIT";
     MESSAGE "EXIT THIS MENU"
*
  ON SELECTION POPUP OVERPASS2 BLANK DO OVERPASS22
  ACTIVATE POPUP OVERPASS2
RETURN
*
PROCEDURE OVERPASS22
   DO CASE
     CASE BAR()=3
         LKCODE="0KO*"
         DO WIN_CODE
         ICODE="0KO          "
         CFIELD="H_OVERPASS"
         SA="Hwy-Overpass"
         DO WIN_DATA2
     CASE BAR()=4
         LKCODE="1KO*"
         DO WIN_CODE
         ICODE="1KO          "
         SA="Mag-Overpass"
         CFIELD="M_OVERPASS"
         DO WIN_DATA2
     CASE BAR()=5
         LKCODE="0KOS*"
         DO WIN_CODE
         ICODE="0KOS         "
         CFIELD="H_OVERPASS"
         SA="Sp-Overpass"
         DO WIN_DATA2
     CASE BAR()=7
         DO COSTEDIT
     CASE BAR()=8
         DO CODEEDIT
     CASE BAR()=9
         DEACTIVATE POPUP
   ENDCASE
RETURN
*
*
*--- DEFINE FACILITY1 POPUP
PROCEDURE FACILITY1
  SET BORDER TO DOUBLE
  DEFINE POPUP FACILITY2 FROM 7,21
  SET COLOR OF BOX TO R/B
  DEFINE BAR 1 OF FACILITY2 PROMPT "     * LEVEL 1 *" SKIP
  DEFINE BAR 2 OF FACILITY2 PROMPT REPLICATE (CHR(205),22) SKIP
  DEFINE BAR 3 OF FACILITY2 PROMPT "Stations";
     MESSAGE "SELECT STATIONS"
  DEFINE BAR 4 OF FACILITY2 PROMPT "Maintenance Facilities";
     MESSAGE "SELECT MAINTENANCE FACILITIES"
  DEFINE BAR 5 OF FACILITY2 PROMPT "Operation Facilities";
        MESSAGE "SELECT OPERATION FACILITIES"
  DEFINE BAR 6 OF FACILITY2 PROMPT REPLICATE (CHR(196),22) SKIP
  DEFINE BAR 7 OF FACILITY2 PROMPT "View/Edit Unit Costs";
     MESSAGE "VIEW/EDIT UNIT COST DATABASE"
  DEFINE BAR 8 OF FACILITY2 PROMPT "View/Edit Code File";
     MESSAGE "VIEW/EDIT CODE FILE"
  DEFINE BAR 9 OF FACILITY2 PROMPT "EXIT";
     MESSAGE "EXIT THIS MENU"
*
  ON SELECTION POPUP FACILITY2 BLANK DO FACILITY22
  ACTIVATE POPUP FACILITY2
RETURN
*
PROCEDURE FACILITY22
   DO CASE
     CASE BAR()=3
         LKCODE="1KFS*"
         DO WIN_CODE
         ICODE="1KFS           "
         CFIELD="STATIONS"
         SA="Stations"
         DO WIN_DATA2
     CASE BAR()=4
         LKCODE="1KFM*"
         DO WIN_CODE
         ICODE="1KFM           "
         SA="Maint. Bld"
         CFIELD="FACILITIES"
         DO WIN_DATA2
     CASE BAR()=5
```

```
         LKCODE="1KFO*"
         DO WIN_CODE
         ICODE="1KFO          "
         CFIELD="FACILITIES"
         SA="Office Bldgs"
         DO WIN_DATA2
     CASE BAR()=7
         DO COSTEDIT
     CASE BAR()=8
         DO CODEEDIT
     CASE BAR()=9
         DEACTIVATE POPUP
   ENDCASE
RETURN
*
*
*--- DEFINE STRUCT1 POPUP
PROCEDURE STRUCT1
  SET BORDER TO DOUBLE
  DEFINE POPUP STRUCT2 FROM 4,20
  SET COLOR OF BOX TO R/B
  DEFINE BAR 1 OF STRUCT2 PROMPT "     * LEVEL 1 *" SKIP
  DEFINE BAR 2 OF STRUCT2 PROMPT REPLICATE (CHR(205),21) SKIP
  DEFINE BAR 3 OF STRUCT2 PROMPT "Tunnel";
     MESSAGE "SELECT TUNNELS FOR MAGLEV"
  DEFINE BAR 4 OF STRUCT2 PROMPT "Cut and Cover";
     MESSAGE "SELECT MAGLEV CUT AND COVER STRUCTURES"
  DEFINE BAR 5 OF STRUCT2 PROMPT "Long Bridge";
        MESSAGE "SELECT LONG BRIDGE STRUCTURES"
  DEFINE BAR 6 OF STRUCT2 PROMPT "Embankment";
        MESSAGE "SELECT EMBANKMENT STRUCTURES"
  DEFINE BAR 7 OF STRUCT2 PROMPT "Noise Wall";
        MESSAGE "SELECT NOISE-WALL STRUCTURES"
  DEFINE BAR 8 OF STRUCT2 PROMPT "Access Road";
        MESSAGE "SELECT ACCESS ROADS"
  DEFINE BAR 9 OF STRUCT2 PROMPT "Fencing";
        MESSAGE "SELECT FENCING"
*  DEFINE BAR 10 OF STRUCT2 PROMPT "Utility Relocation";
*        MESSAGE "SELECT UTILITY RELOCATION"
  DEFINE BAR 10 OF STRUCT2 PROMPT REPLICATE (CHR(196),21) SKIP
  DEFINE BAR 11 OF STRUCT2 PROMPT "View/Edit Unit Costs";
     MESSAGE "VIEW/EDIT UNIT COST DATABASE"
  DEFINE BAR 12 OF STRUCT2 PROMPT "View/Edit Code File";
     MESSAGE "VIEW/EDIT CODE FILE"
  DEFINE BAR 13 OF STRUCT2 PROMPT "EXIT";
     MESSAGE "EXIT THIS MENU"

  ON SELECTION POPUP STRUCT2 BLANK DO STRUCT22
  ACTIVATE POPUP STRUCT2
RETURN
*
PROCEDURE STRUCT22
```

```
   DO CASE
     CASE BAR()=3
         LKCODE="1KST*"
         DO WIN_CODE
         ICODE="1KST          "
         CFIELD="TUNNEL"
         SA="Tunnel"
         DO WIN_DATA
     CASE BAR()=4
         LKCODE="1KSC*"
         DO WIN_CODE
         ICODE="1KSC          "
         SA="Cut & Cover"
         CFIELD="TUNNEL"
         DO WIN_DATA
     CASE BAR()=5
         LKCODE="1KSB*"
         DO WIN_CODE
         ICODE="1KSB          "
         CFIELD="STRUCTURE"
         SA="Long Bridge"
         DO WIN_DATA
     CASE BAR()=6
         LKCODE="1KSE*"
         DO WIN_CODE
         ICODE="1KSE          "
         CFIELD="EMBANKMENT"
         SA="Embankment"
         DO WIN_DATA
     CASE BAR()=7
         LKCODE="1KSN*"
         DO WIN_CODE
         ICODE="1KSN          "
         SA="Noise-Wall"
         CFIELD="NOISE_WALL"
         DO WIN_DATA
     CASE BAR()=8
         LKCODE="1KSR*"
         DO WIN_CODE
         ICODE="1KSR          "
         CFIELD="ROAD"
         SA="Access Road"
         DO WIN_DATA
     CASE BAR()=9
         LKCODE="1KSF*"
         DO WIN_CODE
         ICODE="1KSF          "
         SA="Fencing"
         CFIELD="FENCING"
         DO WIN_DATA
*    CASE BAR()=10
*        LKCODE="1KSU*"
*        DO WIN_CODE
*        ICODE="1KSU         "
*        CFIELD="UTILITY"
*        SA="Utility Relocate"
*        DO WIN_DATA
     CASE BAR()=11
         DO COSTEDIT
     CASE BAR()=12
         DO CODEEDIT
     CASE BAR()=13
         DEACTIVATE POPUP
   ENDCASE
RETURN
*
*--- DEFINE TRAINSET1 POPUP
PROCEDURE TRAINSET1
  SET BORDER TO DOUBLE
  DEFINE POPUP TRAINSET2 FROM 7,21
  SET COLOR OF BOX TO R/B
  DEFINE BAR 1 OF TRAINSET2 PROMPT "     * LEVEL 1 *" SKIP
  DEFINE BAR 2 OF TRAINSET2 PROMPT REPLICATE (CHR(205),21) SKIP
  DEFINE BAR 3 OF TRAINSET2 PROMPT "Operation Trainsets";
     MESSAGE "SELECT MAGLEV TRAINSETS"
  DEFINE BAR 4 OF TRAINSET2 PROMPT "Maintenance Trainsets";
     MESSAGE "SELECT MAINTENANCE TRAINSETS"
  DEFINE BAR 5 OF TRAINSET2 PROMPT REPLICATE (CHR(196),21) SKIP
  DEFINE BAR 6 OF TRAINSET2 PROMPT "View/Edit Unit Costs";
     MESSAGE "VIEW/EDIT UNIT COST DATABASE"
  DEFINE BAR 7 OF TRAINSET2 PROMPT "View/Edit Code File";
     MESSAGE "VIEW/EDIT CODE FILE"
  DEFINE BAR 8 OF TRAINSET2 PROMPT "EXIT";
     MESSAGE "EXIT THIS MENU"
*
  ON SELECTION POPUP TRAINSET2 BLANK DO TRAINSET22
  ACTIVATE POPUP TRAINSET2
RETURN
*
PROCEDURE TRAINSET22
   DO CASE
     CASE BAR()=3
         LKCODE="1KTO*"
         DO WIN_CODE
         ICODE="1KTO       "
         CFIELD="TRAINSET"
         SA="Trainsets"
         DO WIN_DATA3
     CASE BAR()=4
         LKCODE="1KTM*"
         DO WIN_CODE
         ICODE="1KTM       "
         SA="Trainsets"
         CFIELD="TRAINSET"
         DO WIN_DATA3
     CASE BAR()=6
         DO COSTEDIT
     CASE BAR()=7
         DO CODEEDIT
     CASE BAR()=8
         DEACTIVATE POPUP
   ENDCASE
RETURN
*
*
*--- DEFINE ADJUSTMENT POPUP
PROCEDURE ADJUST1
  SET BORDER TO DOUBLE
  DEFINE POPUP ADJUST2 FROM 7,21
  SET COLOR OF BOX TO R/B
  DEFINE BAR 1 OF ADJUST2 PROMPT "     * LEVEL 1 *" SKIP
  DEFINE BAR 2 OF ADJUST2 PROMPT REPLICATE (CHR(205),21) SKIP
  DEFINE BAR 3 OF ADJUST2 PROMPT "Location";
     MESSAGE "SELECT LOCATION:
URBAN/SUBURBAN/RURAL/INTERSTATE/OTHER"
  DEFINE BAR 4 OF ADJUST2 PROMPT "City";
     MESSAGE "ENTER THE CITY CODE"
  DEFINE BAR 5 OF ADJUST2 PROMPT "Topography";
              MESSAGE "SELECT TOPOGRAPHY:
FLAT/UNDULATING/RUGGED/MOUNTAINOUS/OTHER"
  DEFINE BAR 6 OF ADJUST2 PROMPT "Job Condition";
              MESSAGE "SELECT TOPOGRAPHY:
FLAT/UNDULATING/RUGGED/MOUNTAINOUS/OTHER"
  DEFINE BAR 7 OF ADJUST2 PROMPT REPLICATE (CHR(196),21) SKIP
  DEFINE BAR 8 OF ADJUST2 PROMPT "View/Edit Unit Costs";
     MESSAGE "VIEW/EDIT UNIT COST DATABASE"
  DEFINE BAR 9 OF ADJUST2 PROMPT "View/Edit Code File";
     MESSAGE "VIEW/EDIT CODE FILE"
  DEFINE BAR 10 OF ADJUST2 PROMPT "EXIT";
     MESSAGE "EXIT THIS MENU"
*
  ON SELECTION POPUP ADJUST2 BLANK DO ADJUST22
  ACTIVATE POPUP ADJUST2
RETURN
*
PROCEDURE ADJUST22
   DO CASE
     CASE BAR()=3
         LKCODE="XXX"
         DO WIN_CODE
         ICODE="          "
         CFIELD="LOCATION"
         SA="Location"
         DO WIN_DATA
     CASE BAR()=4
         LKCODE="XXX"
         DO WIN_CODE
         ICODE="          "
         CFIELD="CITY"
         SA="City"
         DO WIN_DATA
     CASE BAR()=5
         LKCODE="XXX"
         DO WIN_CODE
         ICODE="          "
         SA="Topography"
         CFIELD="TOPOGRAPHY"
         DO WIN_DATA
     CASE BAR()=6
         LKCODE="XXX"
         DO WIN_CODE
         ICODE="          "
         SA="Job Condition"
         CFIELD="JOB_COND"
         DO WIN_DATA
     CASE BAR()=8
         DO COSTEDIT
     CASE BAR()=9
         DO CODEEDIT
     CASE BAR()=10
         DEACTIVATE POPUP
   ENDCASE
RETURN
*
*
PROCEDURE WIN_CODE
     SET COLOR OF BOX TO R/W
     DEFINE WINDOW W_CODE FROM 3,53.8 TO 22,78 COLOR R/W
     ACTIVATE WINDOW W_CODE
     @ 0,3 SAY "     ITEM CODES" COLOR B/W
     @ 1,0 SAY "  CODE   UNIT  UNITCOST" COLOR B/W
     @ 2,0 SAY "========================" COLOR B/W
     USE &UCFILE
     SET HEADING OFF
     LIST OFF CODE, UNIT, COST FOR LIKE(LKCODE,UPPER(CODE))
     SAVE SCREEN TO SCREEN1
     DEACTIVATE WINDOW W_CODE
     RESTORE SCREEN FROM SCREEN1
     SET COLOR OF BOX TO R/B
     ACTIVATE SCREEN
     *CLOSE DATABASES
RETURN
*
*
PROCEDURE COSTEDIT
     SAVE SCREEN TO SCREEN1
     USE &UCFILE
     SET STATUS ON
     BROWSE
     CLOSE DATABASE
     SET STATUS OFF
     RESTORE SCREEN FROM SCREEN1
     ACTIVATE SCREEN
RETURN
*
*
PROCEDURE CODEEDIT
     SAVE SCREEN TO SCREEN5
     USE &CDFILE
     SET STATUS ON
     BROWSE
     CLOSE DATABASE
     SET STATUS OFF
     RESTORE SCREEN FROM SCREEN5
     ACTIVATE SCREEN
RETURN
*
*
PROCEDURE WIN_DATA
     SAVE SCREEN TO SCREEN1
     SET COLOR OF BOX TO B/W
     DEFINE WINDOW W_DATA FROM 14,18 TO 22,52 COLOR B/W
     ACTIVATE WINDOW W_DATA
     GN=0
     GS=0
     GE=0
     GL=0
     SSAY="No of "+SA+" Sections:"
     SSAY2="For "+SA+" Section:"
     USE &CDFILE
     @ 0,6 SAY "INPUT DATA SCREEN" COLOR R/W
     @ 1,1 SAY SSAY
     @ 1,30 GET GN PICTURE "99"
     READ
     N=1
     DO WHILE N <= GN
         @ 2,3 SAY SSAY2
         @ 2,30 GET N PICTURE "99"
         @ 4,1 SAY "Enter Item Code:"
         @ 4,19 GET ICODE PICTURE "!XXXXXXXXXXX"
         @ 5,1 SAY "Enter Starting Location:"
         @ 5,26 GET GS PICTURE "999.99"
         @ 6,1 SAY "Enter Ending Location:"
         @ 6,26 GET GE PICTURE "999.99"
         READ
         GSI=INT(GS/SECT)
         GEI=INT(GE/SECT)
         REPLACE &CFIELD WITH TRIM(ICODE) FOR SECTION >= GSI;
               .AND. SECTION <= GEI
         GS=0
         GE=0
         N=N+1
     ENDDO
     SA=""
     DEACTIVATE WINDOW W_DATA
     RESTORE SCREEN FROM SCREEN1
     SET COLOR OF BOX TO R/B
     ACTIVATE SCREEN
RETURN
*
*
PROCEDURE WIN_DATA2
     SAVE SCREEN TO SCREEN4
     SET COLOR OF BOX TO B/W
     DEFINE WINDOW W_DATA2 FROM 15,18 TO 22,52 COLOR B/W
     ACTIVATE WINDOW W_DATA2
     GN=0
     GS=0
     *GE=0
     *GL=0
     SSAY="Enter Number of "+SA+":"
     SSAY2="For "+SA+":"
     USE &CDFILE
     @ 0,5 SAY "INPUT DATA SCREEN" COLOR R/W
     @ 1,1 SAY SSAY
     @ 1,30 GET GN PICTURE "99"
     READ
     N=1
     DO WHILE N <= GN
         @ 2,4 SAY SSAY2 GET N PICTURE "99"
         @ 4,1 SAY "Enter Item Code:"
         @ 4,19 GET ICODE PICTURE "!XXXXXXXXXXX"
         @ 5,1 SAY "Enter Location:"
         @ 5,26 GET GS PICTURE "999.99"
         *@ 6,1 SAY "Enter Ending Location:"
         *@ 6,26 GET GE PICTURE "999.99"
         READ
         GSI=INT(GS/SECT)
         IF GSI=0
            GSI=1
         ENDIF
         *GEI=INT(GE/SECT)
         REPLACE &CFIELD WITH TRIM(ICODE) FOR SECTION = GSI
         GS=0
         GE=0
         N=N+1
     ENDDO
     SA=""
     DEACTIVATE WINDOW W_DATA2
     RESTORE SCREEN FROM SCREEN4
     SET COLOR OF BOX TO R/B
     ACTIVATE SCREEN
```

```
RETURN
*
*
PROCEDURE WIN_DATA3
     SAVE SCREEN TO SCREEN5
     SET COLOR OF BOX TO B/W
     DEFINE WINDOW W_DATA3 FROM 15,18 TO 22,52 COLOR B/W
     ACTIVATE WINDOW W_DATA3
     GN=0
     GS=1
     SSAY="Enter Trainset Types:"
     SSAY2="For Trainsets Type:"
     USE &CDFILE
     @ 0,5 SAY "INPUT DATA SCREEN" COLOR R/W
     @ 1,1 SAY SSAY
     @ 1,30 GET GN PICTURE "99"
     READ
     N=1
     DO WHILE N <= GN
         @ 2,4 SAY SSAY2 GET N PICTURE "99"
         @ 4,1 SAY "Enter Trainset Code:"
         *@ 5,1 SAY "Number of Trainsets separated"
         *@ 6,1 SAY "by a Hyphen:"
         @ 4,22 GET ICODE PICTURE "!XXXXXXXXX"
         @5,1 SAY "Enter Number of Trainsets:"
         @5,30 GET GS PICTURE "99"
         READ
         ICODE=TRIM(ICODE)+"-"+LTRIM(STR(GS,2,0))
         REPLACE &CFIELD WITH ICODE FOR SECTION = (N+1)
         GS=1
         *GE=0
         ICODE="1KTO       "
         N=N+1
     ENDDO
     SA=""
     DEACTIVATE WINDOW W_DATA3
     RESTORE SCREEN FROM SCREEN5
     SET COLOR OF BOX TO R/B
     ACTIVATE SCREEN
RETURN
*
*
PROCEDURE FIN
   USE &CDFILE
   REPLACE ALL LOCATION WITH "Suburban" FOR
UPPER(SUBSTR(GUIDEWAY,6,1))="S"
   REPLACE ALL LOCATION WITH "Urban" FOR
UPPER(SUBSTR(GUIDEWAY,6,1))="U"
   REPLACE ALL LOCATION WITH "Rural" FOR
UPPER(SUBSTR(GUIDEWAY,6,1))="R"
   REPLACE ALL LOCATION WITH "Hwy-ROW" FOR
UPPER(SUBSTR(GUIDEWAY,6,1))="I"
```

```
   REPLACE ALL LOCATION WITH "Other" FOR
UPPER(SUBSTR(GUIDEWAY,6,1))="O"
*
   REPLACE ALL TOPOGRAPHY WITH "Flat" FOR
UPPER(SUBSTR(GUIDEWAY,7,1))="F"
   REPLACE ALL TOPOGRAPHY WITH "Undulating" FOR
UPPER(SUBSTR(GUIDEWAY,7,1))="U"
   REPLACE ALL TOPOGRAPHY WITH "Rugged" FOR
UPPER(SUBSTR(GUIDEWAY,7,1))="R"
   REPLACE ALL TOPOGRAPHY WITH "Other" FOR
UPPER(SUBSTR(GUIDEWAY,7,1))="O"
*
   REPLACE ALL JOB_COND WITH "Average" FOR
UPPER(SUBSTR(JOB_COND,1,3))="   "
*
   CLOSE DATABASES
   CLEAR
   DEACTIVATE MENU
RETURN
```

# APPENDIX J
# PRELIMINARY UNIT COST DATABASE COMPILED FROM VARIOUS STUDIES

| MAGLEV GUIDEWAY (KM) | TOTAL (1993$) |
|---|---|
| Single at Grade in Suburban Flat | $4,691,000 |
| Single at Grade in Suburban Undulating | $5,644,000 |
| Single at Grade in Rural Flat | $4,620,000 |
| Single at Grade in Rural Undulating | $5,210,000 |
| Single at Grade in Rural Rugged | $8,023,000 |
| Single at Grade in other ROW Flat | $4,502,000 |
| Single at Grade in other ROW Undulating | $5,870,000 |
| Double at Grade in Suburban Flat | $9,079,000 |
| Double at Grade in Suburban Undulating | $11,697,000 |
| Double at Grade in Rural Flat | $8,680,000 |
| Double at Grade in Rural Undulating | $9,527,000 |
| Double at Grade in Rural Rugged | $12,694,000 |
| Double at Grade in other ROW Flat | $8,558,000 |
| Double at Grade in other ROW Undulating | $10,405,000 |
| At-Grade High Speed Switch (each) | $3,188,000 |
| At-Grade Low Speed Switch (each) | $1,922,000 |
| Double Cut & Cover Tunnel in Urban | $55,988,000 |
| Double Cut & Cover Tunnel in Suburban/Rural | $41,081,000 |
| Single Low-Speed Mined/Bored Tunnel | $32,371,000 |
| Twin Low-Speed Mined/Bored Tunnel | $53,133,000 |
| Single High-Speed Mined/Bored Tunnel | $36,369,000 |
| Twin High-Speed Mined/Bored Tunnel | $61,151,000 |
| Twin Low-Speed Mined/Bored in Mountainous | $55,663,000 |
| Twin High-Speed Mined/Bored in Mountainous | $59,647,000 |

| MAGLEV GUIDEWAY (KM) | TOTAL (1993$) |
|---|---|
| Single Elevated in Suburban Flat | $5,005,000 |
| Single Elevated in Suburban Undulating | $5,524,000 |
| Single Elevated in Rural Flat | $4,871,000 |
| Single Elevated in Rural Undulating | $5,382,000 |
| Single Elevated in Rural Rugged | $6,041,000 |
| Single Elevated in Interstate ROW Flat | $5,370,000 |
| Single Elevated in Interstate ROW Undulating | $5,749,000 |
| Single Elevated in other ROW Flat | $4,809,000 |
| Single Elevated in other ROW Undulating | $5,650,000 |
| Special Single Elevated Structures | $12,295,000 |
| Double Elevated in Urban Flat | $10,184,000 |
| Double Elevated in Suburban Flat | $9,534,000 |
| Double Elevated in Suburban Undulating | $10,221,000 |
| Double Elevated in Rural Flat | $9,302,000 |
| Double Elevated in Rural Undulating | $9,564,000 |
| Double Elevated in Rural Rugged | $10,615,000 |
| Double Elevated in Interstate ROW Flat | $9,716,000 |
| Double Elevated in Interstate ROW Undulating | $10,279,000 |
| Double Elevated in other ROW Flat | $9,166,000 |
| Double Elevated in other ROW Undulating | $10,132,000 |
| Special Double Elevated Structures | $19,614,000 |
| Elevated High Speed Switch (each) | $3,241,000 |
| Elevated Low Speed Switch (each) | $1,949,000 |

| NAME | UNIT | UNIT COST |
|---|---|---|
| | | ($1993-million) |
| MAGLEV GUIDEWAY | | |
| Guideway: At-Grade | KM | 2.990 |
| Guideway: 6 m high | KM | 3.722 |
| Guideway: 9 m high | KM | 4.258 |
| Guideway: 12 m high | KM | 4.825 |
| Guideway: 15 m high | KM | 5.422 |
| Guideway Beam | KM | 2.401 |
| Low Speed Switch | EACH | 1.230 |
| Switches: 3-way | EACH | 2.160 |
| Column and Pile Foundation | KM | 1.150 |
| Footings | KM | 0.683 |
| OTHER STRUCTURES | | |
| Tunnel: Moderate 2x8.2 m Diameter | KM | 39.405 |
| Tunnel: Difficult: 2x8.2 m Diameter | KM | 43.900 |
| Undergroung Crossing | KM | 132.420 |
| Overpass | EACH | 0.610 |
| Access Road | KM | 0.185 |
| EQUIPMENTS | | |
| Guideway's Long Stator | KM | 1.700 |
| Wayside Equipments | SECTIO | 5.710 |
| ELECTRIFICATION | | |
| Power Supply | KM | 1.043 |
| Power Substation | MVA | 0.188 |
| Substation Construction | EACH | 1.810 |
| Power Line Feeder | KM | 0.267 |
| Motor Switches | MODUL | 0.205 |
| Signalling Equipment | KM | 3.310 |

| NAME | UNITS | UNIT COST<br>($1993-million) |
|---|---|---|
| RAILROAD BRIDGES | | |
| Trestle: Canal: Single | EACH | 0.227 |
| Trestle: Canal: Dual | EACH | 0.387 |
| Trestle: Wetlands: Single | KM | 5.171 |
| Trestle: Wetlands: Dual | KM | 9.028 |
| Elev. Struct.:16.5':Single | KM | 7.754 |
| Elevated Struct.:23':Single | KM | 7.973 |
| Elevated Struct.:23':Single | KM | 8.668 |
| Elevated Struct.:50':Single | KM | 9.087 |
| Bascule Bridge: New | EACH | 2.416 |
| Elevated Structure: Triple | KM | 15.305 |
| RAILROAD EARTHWORK | | |
| RR Embank.:16.5:Dual:w/o walls | EACH | 1.410 |
| RR Embank.: 16.5:Dual:w/ walls | EACH | 2.103 |
| RR Embank.:23:Dual:w/o walls | EACH | 2.454 |
| RR Embankment:23:Dual:w/walls | EACH | 1.733 |
| RR Embank:Standard Section:Single | KM | 0.350 |
| RR Embank:Standard Section:Dual | KM | 0.543 |
| Retaining Wall: 7' High: One Side | KM | 1.491 |
| RR Embank.:Elev. Section:16.5':S | KM | 2.933 |
| RR Excavation: With Walls | KM | 10.435 |
| RR Excavation: Special | KM | 9.981 |
| Cut to Fill: Rock | M.CM | 6.443 |
| Cut to Disposal: Rock | M.CM | 11.045 |
| Clear and Grub: Timber | ACRE | 4.440 |
| Clear and Grub: Brush | ACRE | 1.560 |

| NAME | UNIT | UNIT COST |
|---|---|---|
| | | ($1993-million) |
| TRACK | | |
| Freight Crossover | EACH | 0.126 |
| New HSR Track: Dual | KM | 0.672 |
| New HSR Track: Single | KM | 0.338 |
| New Freight Track: Single | KM | 0.337 |
| Upgrade Freight Track: Single | KM | 0.166 |
| Spur Track Connection | EACH | 0.060 |
| Low Speed Turnout Track: #20 | EACH | 0.060 |
| High Speed Turnout Track | EACH | 0.302 |
| At Grade Track Crossing: Minor | EACH | 0.181 |
| At Grade Track Crossing: Major | EACH | 0.604 |
| Freight Track Removal | KM | 0.007 |
| UTILITY RELOCATION | | |
| Utility Relocation: General | KM | 0.086 |
| Utility Relocation: Major | EACH | 0.885 |
| MISCELLANEOUS | | |
| At Grade Crossing: Minor: 2 Lane | EACH | 0.181 |
| At Grade Crossing: Major | EACH | 0.302 |
| Fence: FDOT Type "A" | KM | 0.009 |
| Fence: FDOT Type "B" | KM | 0.023 |
| Noise Barrier: Wall | KM | 0.255 |
| Drainage: Urban | KM | 0.237 |
| Drainage: Rural | KM | 0.174 |
| Road Closing: Local | EACH | 0.000 |
| New Access Road: Public | KM | 0.279 |
| Service Road: Gravel | KM | 0.083 |
| Relocate Track | KM | 0.065 |
| Maintenance Facility: small | EACH | 13.500 |
| Maintenance Facility: major | EACH | 30.100 |

| NAME | UNITS | UNIT COST<br>($1993-million) |
|---|---|---|
| ELECTRIFICATION | | |
| Electrification New Single | KM | 0.367 |
| Electrification (additional Track) | KM | 0.149 |
| SIGNALIZATION | | |
| Signalization New Single | KM | 0.424 |
| Signalization New (additional track) | KM | 0.018 |
| Signalization CSX Single | KM | 0.429 |
| Signalization CSX Additional Track | KM | 0.015 |
| ROADWAY BRIDGES | | |
| Lengthen Overpass: 2 Lane | EACH | 0.604 |
| Lengthen Overpass: 4 Lane | EACH | 0.917 |
| Lengthen Overpass: 4 Lane Divided | EACH | 1.136 |
| Lengthen Overpass: 4 Lane Divided Speci | EACH | 4.000 |
| Embank Modification: 2 Lane | EACH | 0.243 |
| Embank Modification: 4 Lane | EACH | 0.294 |
| Embank Modification: 4 Lane Divided | EACH | 0.345 |
| New Overpass: without walls: 2 Lane-Sp | EACH | 3.204 |
| New Overpass: without walls:2 Lane-Typ | EACH | 3.039 |
| New Overpass: without walls: 4 Lane-Sp | EACH | 4.155 |
| New Overpass: without walls:4 Lane-Typ | EACH | 3.880 |
| New Overpass:without walls:4 Lane Div-Sp | EACH | 4.979 |
| New Overpass:without walls:4 Lane Div-Ty | EACH | 4.596 |
| New Overpass: without walls:6-8 Lane-Sp | EACH | 7.363 |
| New Overpass: with walls: 4 Lane - Typical | EACH | 5.950 |

# APPENDIX K
# RELATED CORRESPONDENCE

HIGH SPEED RAIL/MAGLEV
ASSOCIATION

May 6, 1993

Fadi Emil Nassar
University of Florida
Civil Engineering Dept.
346 Weil Hall
Gainesville, FL 32611

Dear Mr. Nassar:

Thank you very much for your letter and your kind comments about SPEEDLINES. Enclosed with this letter are maps and other materials which you might find useful for your paper. Unfortunately, we no longer supply photos of specific trains or train systems because the demand was too great for us to handle.

I would be quite interested in your analysis and comparison of steel-wheel high speed rail and maglev high speed rail systems. (We consider all systems that travel at high speeds to be "high speed rail" including maglev systems so we make the distinction by referring to steel-wheel systems). When I served as executive director of the Pennsylvania High Speed Intercity Rail Commission, our three-year $4 million dollar study indicated that, "for Pennsylvania at least, it would be less expensive to build a Philadelphia-Pittsburgh maglev system than a steel-wheel system." This is because to build a steel-wheel system, it would be necessary to construct numerous tunnels through the Allegheny Mountains. No tunnels at all would be required for the maglev system because of its great climbing ability and higher speeds.

After our convention, which is May 23-26 in Toronto, please call me and we can discuss this in more detail. If possible please send me a copy of your dissertation.

Sincerely,

Bob Casey

Robert J. Casey
Vice Chairman

RJC/psf

Enclosures

*206 Valley Court, Suite 800, Pittsburgh, PA 15237 (412) 364-9306*

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26. RUE D'ORADOUR SUR GLANE 75504 PARIS CEDEX 15 TEL (1) 44 25 30 01 FAX (1) 45 58 15 19

from Dr. Michel Le Toullec, Editor
Industries et Techniques, (tel 44 25 33 54; fax 45 58 15 19)

to Fadi Nassar,
University of Florida

Dear Fadi,

In reference to the article I am preparing on the high speed trains projects in the USA, let me thank you for the amount of documentation you sent me, and also for the expertise you gave me on this very specific topic. All those informations are indeed very precious for my work. The paper is scheduled to be published in one of the october or november issues of the magazine. You will of course receive that issue.

I would also appreciate if you could let me know the evolution of your research before you thesis and even after. Do not hesitate to contact me if you need some further informations on the TGV, and also if you happen to come to France.

I'm looking forward to seeing you

Paris, September 30
Michel Le Toullec

# BIOGRAPHICAL SKETCH

Fadi Emil Nassar was born in Lebanon where he obtained his high-school diploma from the *Frères Mont La Salle* Catholic School. Later he went to Europe where he studied two years of business (*ingénieur commercial*) at the *École de Solvay, Université Libre de Bruxelles*, in Belgium.

In December 1982, he came to the United States and three years later he obtained his Bachelor of Science degree in civil engineering with honors from the Florida Institute of Technology. He later transferred to the University of Florida where he obtained a Master of Engineering degree in 1989.

He has served as a student member of the American Society of Civil Engineers, the High Speed Rail/Maglev Association, the Transportation Research Board, and the Institute of Transportation Engineers. Beside engineering, his main interests are history and philosophy.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Fazil T. Najafi, Chairman
Associate Professor of Civil Engineering

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Paul Y. Thompson
Professor of Civil Engineering

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Ralph D. Ellis

Ralph D. Ellis
Assistant Professor of Civil Engineering

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Joseph A. Wattleworth
Professor of Civil Engineering

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Sharma Chakravarthy
Associate Professor of Computer And
Information Sciences

This dissertation was submitted to the Graduate Faculty of the College of Engineering and the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

August, 1993

Winfred M. Phillips
Dean, College of Engineering

Dean, Graduate School

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